PUBLICATION 819
TECHNICAL BULLETIN 71
ISSUED JUNE, 1949
DOMINION OF CANADA—DEPARTMENT OF AGRICULTURE

SOIL MOISTURE, WIND EROSION AND FERTILITY OF SOME CANADIAN PRAIRIE SOILS

SOIL RESEARCH LABORATORY
Swift Current, Sask.

DIVISION OF FIELD HUSBANDRY, SOILS AND AGRICULTURAL ENGINEERING
EXPERIMENTAL FARMS SERVICE

...hed by Authority of the Right Hon. James G. Gardiner, Minister of Agriculture
Ottawa, Canada

—6:49

SOIL RESEARCH LABORATORY

STAFF

J. L. DOUGHTY, Ph.D.,
Officer-in-charge

W. J. STAPLE, Ph.D.

J. J. LEHANE, M.S.A.

F. G. WARDER, M.Sc.

F. BISAL, M.Sc.

Acknowledgment is made to W. S. Chepil, Ph.D. and R. A. Milne, B.S.A., former members of the staff, for their part in the Laboratory work. Dr. Chepil was in charge of the wind erosion and weed seed dormancy studies.

TABLE OF CONTENTS

29171—1

INTRODUCTION

The Soil Research Laboratory, which was established by authority of the Prairie Farm Rehabilitation Act of 1935, is now a part of the Experimental Farms Service, Dominion Department of Agriculture.

The present publication is the third of a series dealing with the problems of soil moisture, soil fertility, and soil erosion. The subject matter deals, in general, with the brown and dark brown soils of the Prairie Provinces and particularly with the soils and climatic conditions of southwestern Saskatchewan.

The first bulletin (3) of this series published in 1938 covered the soil moisture investigations that had been carried on at the Swift Current Experimental Station prior to the establishment of the Laboratory. The second bulletin (39) published in 1943 covered the first five years work of the Laboratory as well as pertinent data published previously. Data are presented in this Bulletin covering some projects that have been under way for 20 years or more during which there has been a wide variation in climatic conditions. The main period covered, however, is 1943 to 1947. Reference is made throughout the text to published articles, which give more detail in regard to methods and results than could be included in a publication of this nature.

PRECIPITATION AND EVAPORATION

Swift Current is located in southwestern Saskatchewan in an area of low precipitation, low relative humidity and high evaporation. These climatic factors determine the type of agriculture that must be followed.

The average precipitation and evaporation, as recorded at the Dominion Experimental Farms and Stations in the Prairie Provinces, are shown in Fig. 1. This gives a partial picture of the climatic condition to which crops are subjected at the different locations. The high evaporation at Swift Current makes crop production more hazardous than at locations with similar precipitation but lower evaporation.

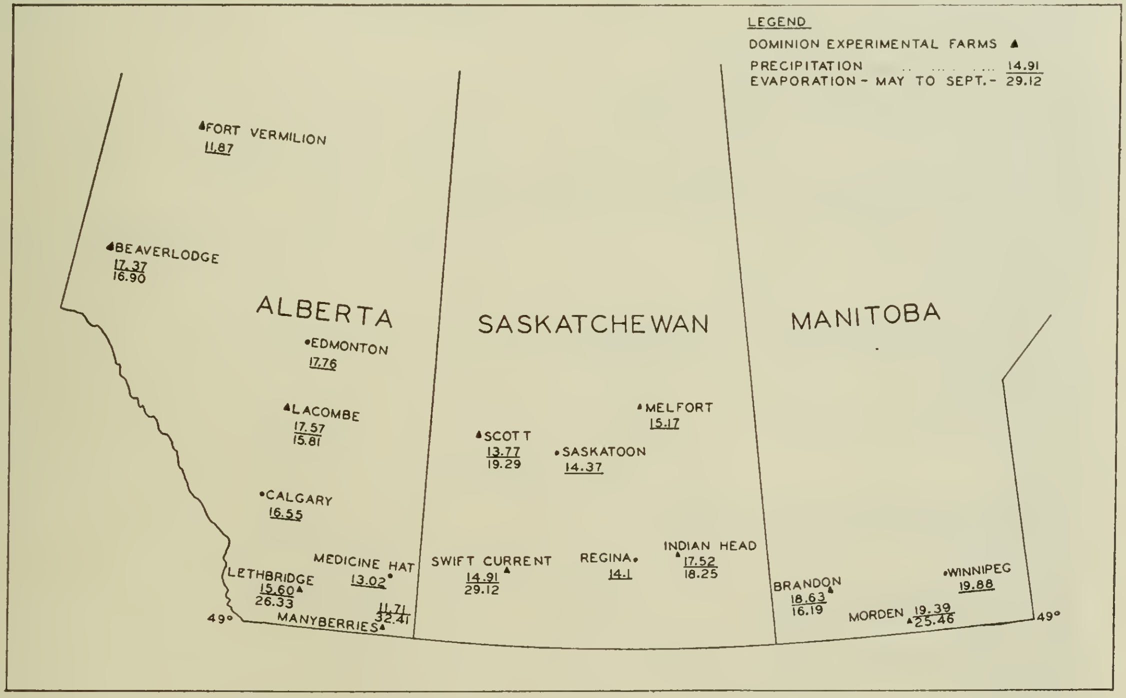


Fig. 1.—Precipitation and evaporation in the prairie provinces.

29171—1½

The average annual precipitation at Swift Current for the past 62 years, as shown in Fig. 2, has been 14·91 inches with a high of 24·55 inches in 1891 and a low of 8·26 inches in 1937. The data do not show any definite cycle of wet and dry years nor indicate that precipitation is becoming less. It is evident that years of low precipitation are of frequent occurrence.

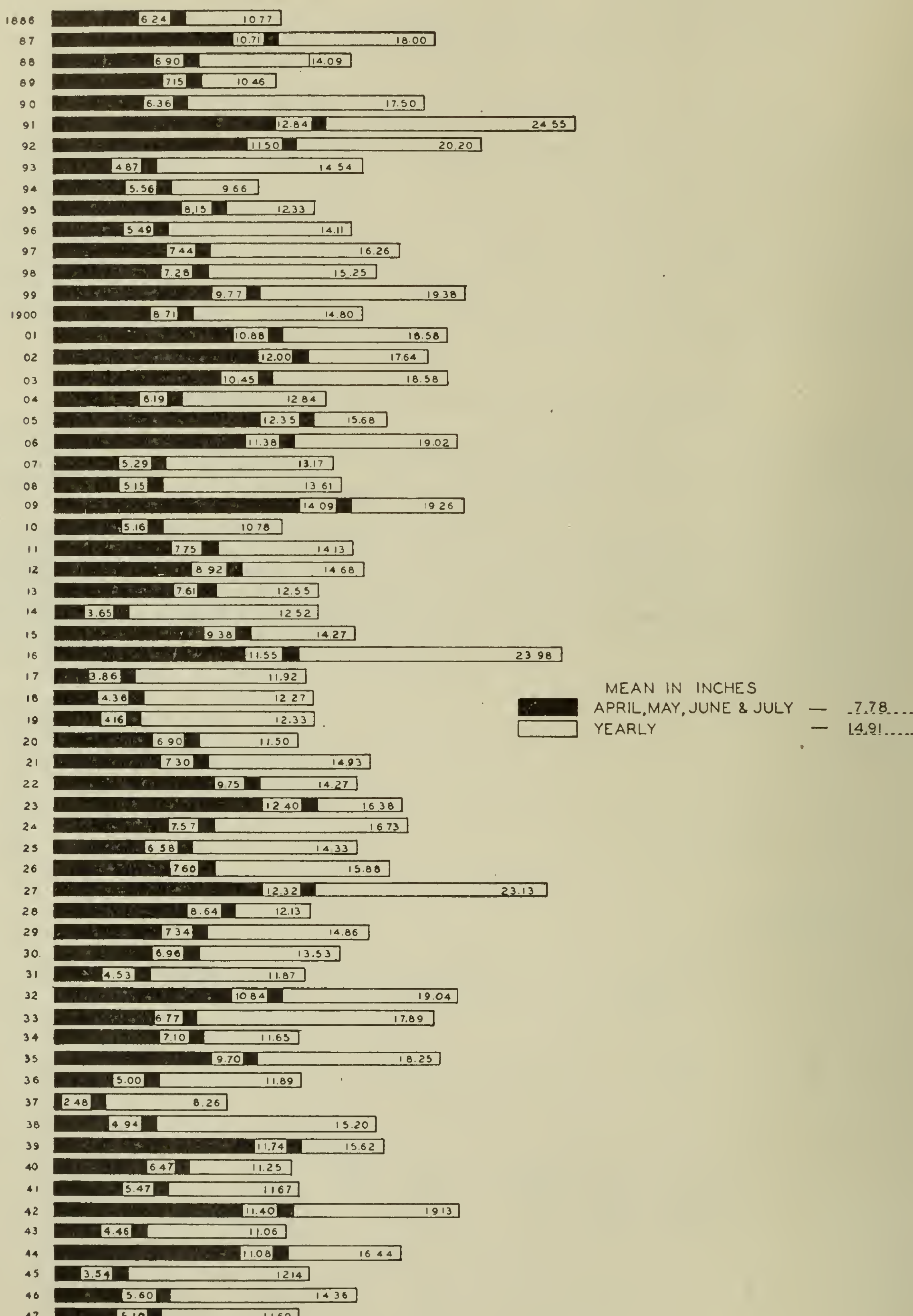


Fig. 2.—Annual and average precipitation at Swift Current.

The months of April, May, June and July are referred to as the growing season for this is the period of most rapid growth of plants. During this period the average precipitation has been 7·78 inches, which is 52·1 per cent of the total. This favourable distribution makes cereal production possible but it is essential that cultural operations be planned to conserve the maximum amount of moisture for in only 22 of the 62 years recorded was the seasonal precipitation equal to or above the mean of 7·78 inches.

Evaporation records show an average evaporation of 29·12 inches during the months of May, June, July, August and September for the past 26 years. The highest evaporation was 41·08 inches in 1937 and the lowest 23·18 inches in 1923. These figures represent evaporation from the free water surface of a standard evaporation tank 4 feet in diameter and ? feet deep, set level with the ground surface. The year 1937 was outstanding in that the yearly and seasonal precipitation were the lowest on record and the evaporation was the highest. This was likewise the year of lowest crop yield in Saskatchewan.

The average meteorological conditions at this Station for the months of April, May, June, and July are listed in Table 1. June is the month of highest precipitation and is also the month of most rapid plant growth. The cereal crops generally reach the shot blade stage during the third or fourth week in June. The many hours of sunshine and high temperature of July cause a rapid filling of the grain. A lack of moisture during this critical period may seriously reduce the crop yield.

TABLE 1.—METEOROLOGICAL DATA FOR SWIFT CURRENT, 1922–1947

—	April	May	June	July
Precipitation (inches)	0·78	1·62	2·90	1·81
Sunshine (hr./day)	6·8	7·5	7·5	9·7
Air temperature—Mean Max. °F	51·8	64·3	70·6	80·5
Mean Min. °F	29·0	38·8	47·2	52·5
Mean °F	40·4	51·6	58·9	66·5
Wind velocity mi./pr. at 5 foot height*	8·7	8·8	7·6	8·1
Evaporation free-water surface (inches)	....	5·49	5·78	7·43

* 1934–1947 only.

The frequency and intensity of rainfall during the months of April to October for the years 1922 to 1947 are given in Table 2. Daily precipitation of 0·01 inch or more occurred on 1,800 days or approximately every third day. Less than 0·11 inch was recorded on 1,156 days, while 1·01 inches or more was recorded only 39 times.

TABLE 2.—RAINFALL FREQUENCY AND INTENSITY, APRIL TO OCTOBER

1922–1947=5,564 days

Daily precipitation	Times occurring	Daily precipitation	Times occurring
inches		inches	
0·01–0·10	1,156	0·41–0·50	43
0·11–0·20	243	0·51–0·75	71
0·21–0·30	140	0·76–1·00	36
0·31–0·40	72	1·01–	39

Number of days without measurable precipitation—3,764.

The precipitation recorded on 1,539 of the 1,800 days on which rain fell was 0·3 inch or less. Light showers are of little value in increasing the reserve of soil moisture unless the soil is moist to or near the surface. Moisture penetrating 5 inches into the soil is considered relatively safe from loss by evaporation. When heavy showers of short duration occur, there may be some loss by run-off.

SOIL MOISTURE

The water in the soil is divided into three classes, depending on the manner in which it is held. These divisions are more or less arbitrary, each merging into the other with no sharp lines of division.

A small amount of water, which is known as *hygroscopic moisture,* is held by the colloidal material of the soil. The amount so held depends on the degree of saturation of the soil air and the amount of colloidal material. Such moisture does not move from particle to particle except by evaporation and condensation and is of no value to the plant.

As the moisture content of the soil increases, the soil particles are surrounded by thin films of water. These films gradually thicken, and the small spaces between the particles become filled with water. This is known as *capillary moisture,* and is the main source of supply for the plant. Such moisture will move slowly in any direction from a point of high to one of low concentration.

With a further increase in moisture, the large pore spaces become filled, and the water starts to move downward in response to the force of gravity. This is known as *gravitational water.* While the gravitational water is moving downward, each soil particle is saturated in respect to hygroscopic and capillary moisture. The downward movement continues until all the moisture is held by hygroscopic and capillary forces, or until the ground water-table is reached. The rate of downward movement is influenced by the class of soil, being rather slow in a clay and fairly rapid in a sandy soil.

The *field capacity* of a soil designates the maximum amount of water that can be held by a soil after downward movement due to gravity has practically ceased. The amount so held varies according to the type of soil, being directly influenced by the amount of colloidal and organic material. The sandy soils have the lowest field capacity and the clay soils the highest of the mineral soils.

The *wilting point* is another important factor in crop production, for it indicates the moisture content of the soil when the plant permanently wilts. Crop growth may be modified before this point is reached. The difference between the field capacity and the wilting point represents the maximum amount of available moisture that can be stored in a given soil.

Some of the moisture relationships for Haverhill loam soil are shown in Fig. 3. Curve A shows the capillary tension in cm. of mercury obtained at different moisture contents using the porous pot method. Curve B is the approximate pF (logarithm of capillary tension in cm. of water) of the soil based on porous pot data at high moisture contents and on vapour pressure data below the permanent wilting percentage. Curve C is the capillary conductivity calculated from the observed change of the moisture profile with time as water moved from a moist to a dry column of soil. As pointed out by Veihmeyer and Hendrickson (43) and Moore (35) the capillary conductivity falls to a low value when the soil is dried to below the field capacity.

Under field conditions, the crop may draw moisture from the subsoil after the moisture content of the upper layer of soil has been reduced to or below the wilting point. When there is a shortage of available moisture, during the ripening period, the crop may reduce the moisture content below the wilting point to the depth of root penetration. The additional moisture secured after

the wilting point is reached, will not support growth but may aid in the filling of the grain, though the kernels will not be as fully developed as when an adequate supply of available moisture is present.

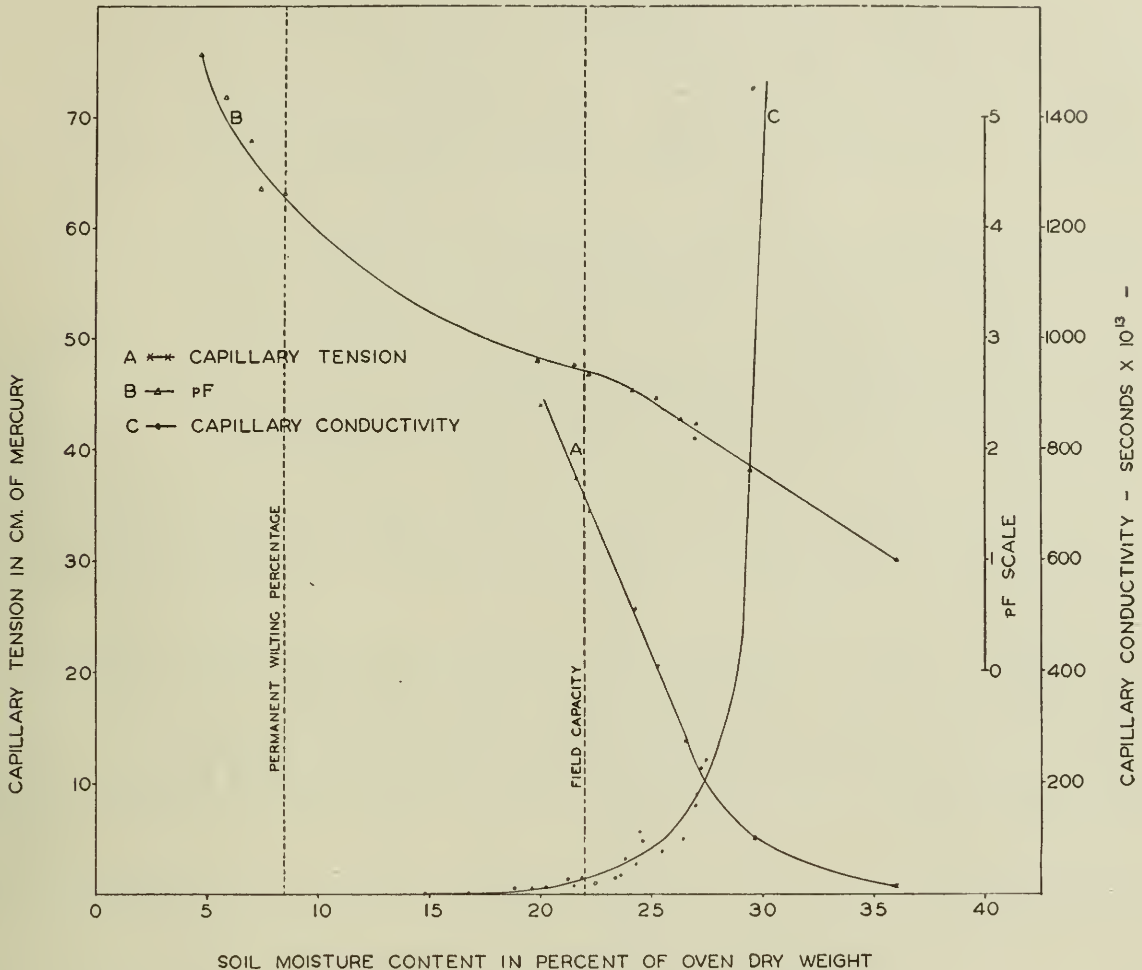


Fig. 3.—Moisture relationships of Haverhill loam.

The calculation of available moisture from wilting point data has proved a satisfactory basis for soil moisture investigations at this Laboratory (41).

The data in Table 3 show the average field capacity, wilting point, and maximum storage capacity of different soil types. As a 20-bushel crop of wheat requires approximately 12 inches of water, it is evident that such a crop cannot be produced by the water stored in 4 feet of soil.

TABLE 3.—AVERAGE FIELD CAPACITY, WILTING POINT, AND STORAGE CAPACITY OF SOILS

Soil type	Field capacity	Wilting point	Normal storage capacity to 4 feet
	per cent	per cent	inches
Sandy loam	10	3·5	4·0
Loam and silt loam	18	7·0	6·2
Clay loam and silty clay loam	26	10·5	7·2
Clay	35	17·0	8·6

Tank Experiments

The use of soil-filled, water-tight tanks for the study of changes in soil moisture was started at this Station in 1922 by Barnes (3). This method was considered as being particularly applicable for determining the use of water by crops and the conservation of moisture by summerfallow. An accurate record of changes in moisture content was obtained by periodic weighing of the tanks.

The tanks are made of galvanized iron, and are 15 inches in diameter and 5 feet deep. They were set in pairs, in pits 5 feet deep so that the soil in the tank was at the same level as the surrounding plot. Each pair of tanks was placed in the center of a 16-foot square plot, which was subject to the same cultural treatment as the tanks. The tanks were filled with uniform, well-mixed soil placed in layers corresponding to the original position *in situ*. An excess of seeds was planted in each tank and the crop thinned to 20 uniform plants which corresponded to an ideal field distribution. As the filled tanks weighed over 600 pounds the increase in weight due to crop growth was negligible. This method of experimentation, although subject to criticism, has yielded some very pertinent data. There is no loss of water or plant nutrients by seepage and likewise no movement of moisture into the tank from the surrounding soil. The roots are restricted to some extent and the tanks do not all benefit to the same extent from moisture derived from snow owing to an uneven accumulation and thawing of snow cover.

The crop yields in the tanks have, in general, been higher than those under field conditions. This is attributed to a more uniform spacing of plants, lack of competition by weeds and elimination of loss at harvest.

Some of the experiments started in 1922 have been continued on the same series of tanks up to the present time, thus giving data for years of varied climatic conditions.

All references to tank experiments in this bulletin refer to this type of experimentation.

Water Conserved by Summerfallow

The general cropping practice on the prairie areas includes a summerfallow at frequent intervals. In the districts where periods of drought are of frequent occurrence, the land is fallowed every second or third year. The main purpose of summerfallow is to conserve moisture, storing in the soil part of the between-crop precipitation for the use of succeeding crops. Moisture conservation implies weed control for weeds use large quantities of water and any weed or other plant growth during the fallow period uses moisture that might have been stored for future crops.

Intertilled crops have been tried as a substitute for summerfallow to overcome the drawback of one year without a crop. This practice has not been satisfactory, for the intertilled crops used practically all the available moisture, thus defeating the main purpose of the summerfallow.

Throughout this bulletin, the crop immediately following a period of summerfallow will be designated as a summerfallow crop, and the crop on land that supported a crop the previous year as a stubble crop.

The percentage of the precipitation that can be conserved by summerfallow varies from year to year, being determined by the intensity of rainfall, weed growth, soil type and cultural practices.

Data are presented in Table 4 showing the conservation of moisture by loam soil in tanks for 23 fallow periods. These figures represent conservation by a loam soil under practically ideal conditions since all weed growth was prevented, the soil was kept in a condition to permit rapid penetration of

moisture, and loss by run-off was reduced to a minimum. The tabulated data record the precipitation and moisture conservation for three successive stages of the fallow period, beginning with the harvest of one crop and proceeding to the seeding of the next, a period of 20 to 21 months. The actual date of harvest and seeding would determine whether all rainfall during August or April was included in compilation of the data. The after-harvest period extends from August to the following April. Then follows the May to October period, during which most of the cultural operations are performed, followed by the winter period, November to April.

TABLE 4.—WATER CONSERVED BY SUMMERFALLOW AT DIFFERENT PERIODS OF THE YEAR

Period	Precipitation	Amount conserved		Total precipitation	Total amount conserved	
	inches	inches	per cent	inches	inches	per cent
Aug. 1923 - April 1924	6·12	1·88	30·7			
May to October, 1924	11·61	4·80	41·3	22·23	7·46	33·6
Nov. 1924 - April 1925	4·50	0·78	17·3			
Aug. 1924 - April 1925	8·40	3·69	44·0			
May to October, 1925	7·97	1·88	23·6	19·28	5·57	28·9
Nov. 1925 - April 1926	2·91	none				
Aug. 1925 - April 1926	7·23	2·80	38·7			
May to October, 1926	10·51	2·45	23·3	23·26	6·66	28·6
Nov. 1926 - April 1927	5·52	1·41	25·5			
Aug. 1926 - April 1927	10·05	4·71	46·9			
May to October, 1927	13·93	5·80	41·6	26·25	10·51	40·0
Nov. 1927 - April 1928	2·27	none				
Aug. 1927 - April 1928	5·51	1·57	28·5			
May to October, 1928	8·47	3·11	36·7	17·29	4·68	27·1
Nov. 1928 - April 1929	3·31	none				
Aug. 1928 - April 1929	4·15	0·38	9·2			
May to October, 1929	7·76	2·64	34·0	15·67	3·69	23·5
Nov. 1929 - April 1930	3·76	0·67	17·8			
Aug. 1929 - April 1930	5·40	2·04	37·8			
May to October, 1930	9·10	3·50	38·5	16·09	5·54	34·4
Nov. 1930 - April 1931	1·59	none				
Aug. 1930 - April 1931	5·85	2·54	43·4			
May to October, 1931	7·22	2·33	32·3	17·60	5·41	30·7
Nov. 1931 - April 1932	4·53	0·54	11·9			
Aug. 1931 - April 1932	6·86	1·32	19·2			
May to October, 1932	12·14	4·38	36·1	20·73	6·01	29·0
Nov. 1932 - April 1933	1·73	0·31	17·9			
Aug. 1932 - April 1933	6·29	1·63	25·9			
May to October, 1933	10·33	3·63	35·1	18·52	5·26	28·4
Nov. 1933 - April 1934	1·90	none				
Aug. 1933 - April 1934	7·92	2·67	33·7			
May to October, 1934	8·07	1·49	18·5	20·08	4·16	20·7
Nov. 1934 - April 1935	4·09	none				
Aug. 1934 - April 1935	6·95	1·26	18·1			
May to October, 1935	6·70	2·31	34·5	21·01	4·07	19·4
Nov. 1935 - April 1936	7·36	0·50	6·8			
Aug. 1935 - April 1936	6·55	0·90	13·7			
May to October, 1936	5·55	0·59	10·6	14·07	1·49	10·6
Nov. 1936 - April 1937	1·97	none				
Aug. 1936 - April 1937	4·87	0·30	6·2			
May to October, 1937	4·78	0·12	2·5	16·57	3·56	21·5
Nov. 1937-April 1938	6·92	3·14	45·4			

TABLE 4.—WATER CONSERVED BY SUMMERFALLOW AT DIFFERENT PERIODS OF THE YEAR—*Concluded*

Period	Preci-pitation	Amount conserved		Total pre-cipitation	Total amount conserved	
	inches	inches	per cent	inches	inches	per cent
Aug. 1937 - April 1938	8·75	3·15	36·0			
May to October, 1938	8·13	1·18	14·5	20·77	4·33	20·8
Nov. 1938 - April 1939	3·89	none				
Aug. 1938 - April 1939	8·74	2·83	32·4			
May to October, 1939	11·86	5·34	45·0	24·48	8·87	36·2
Nov. 1939 - April 1940	3·88	0·70	18·0			
Aug. 1939 - April 1940	4·54	1·73	38·1			
May to October, 1940	7·45	0·83	11·1	14·65	2·86	19·5
Nov. 1940 - April 1941	2·66	0·30	11·3			
Aug. 1940 - April 1941	5·00	0·94	18·8			
May to October, 1941	8·35	0·90	10·8	18·41	3·84	20·9
Nov. 1941 - April 1942	5·06	2·00	39·5			
Aug. 1941 - April 1942	9·21	3·07	33·3			
May to October, 1942	14·86	6·77	45·6	27·57	9·84	35·7
Nov. 1942 - April 1943	3·50	none				
Aug. 1942 - April 1943	8·04	2·54	31·6			
May to October, 1943	7·78	1·05	13·5	19·26	3·59	18·6
Nov. 1943 - April 1944	3·44	none				
Aug. 1943 - April 1944	6·90	4·17	60·4			
May to October, 1944	12·39	2·61	21·1	23·63	6·78	28·7
Nov. 1944 - April 1945	4·34	none				
Aug. 1944 - April 1945	6·55	1·29	19·7			
May to October, 1945	7·21	1·81	25·1	17·59	3·10	17·6
Nov. 1945 - April 1946	3·83	none				
Aug. 1945 - April 1946	8·07	3·07	38·0			
May to October, 1946	9·86	2·21	22·4	22·33	5·28	23·6
Nov. 1946 - April 1947	4·40	none				
Average	....	....	....	19·88	5·33	26·8

The data in Table 4 show that the average precipitation for the fallow period was 19·88 inches of which 5·33 inches or 26·8 per cent was conserved. The importance of fall rains and snow is shown by an average conservation of 2·19 inches during the August to April period. This is attributed in part to the dry soil at harvest time and the low evaporation during this part of the year. This moisture is the result of rain or snow that fell from 12 to 21 months prior to the seeding of the summerfallow crop. During the period of cultural operations, May to October, the average conservation was 2·68 inches. Any weed growth during this period would reduce this amount considerably. There was very little increase in soil moisture due to snowfall during the November-April period. Under field conditions, it has been found that the winter snow in some years may have an appreciable effect on the moisture content of fallowed land. Such factors as depth of snow, rate of thawing and depth of frozen soil, all have an influence on the amount of moisture conserved. Fields, which have produced a crop the previous season, benefit more from late fall rains and winter snow than fallow fields. The same effect was found in the tank experiments.

The information obtained from this experiment emphasizes the necessity of obtaining the maximum storage possible, for under the very best conditions the maximum conservation is approximately one-quarter of the precipitation.

Effect of Rainfall Distribution on Moisture Conservation in Summerfallow

The loss of moisture by evaporation from the soil is one of the main factors in determining the amount conserved in summerfallow. Hopkins (30), in a statistical analysis of data obtained from the summerfallow tanks at Swift Current for the years 1922-1938, found that, under average conditions, rain in the amount of 0·36 inch in May or June and 0·46 inch in July or August, was required to offset the subsequent evaporation in a 10-day period. He found also that 66 per cent of a one-day rain of 1 inch in May or June would still be conserved if the rain occurred in five daily showers of 0·2 inch.

A method was developed at this Laboratory for estimating moisture conservation in summerfallow land by the use of daily records of precipitation and free-water evaporation (42). A series of experimental curves were obtained showing the loss by evaporation when different quantities of water were added to soils of different initial moisture content. The estimated evaporation loss from fallowed fields was obtained from the appropriate experimental curves when the different combinations of initial moisture content and rainfall were reproduced under natural conditions. The moisture conserved was assumed to be the difference between precipitation and evaporation, run-off being neglected.

The loss of moisture by evaporation from Haverhill loam soil, moistened to above the field capacity, is shown by the upper curve of Fig. 4. The shape of this curve is similar to that obtained by Fisher (29), Keen (32), Penman (38), and others in the drying of soils. The curve is characterized by an initial constant rate period followed by a decreasing rate period. The rapid initial loss occurs while the surface is wet and the rate is approximately the same as from a free-water surface. The evaporation rate is reduced when the moisture content of the soil falls below the field capacity and a dry layer forms at the

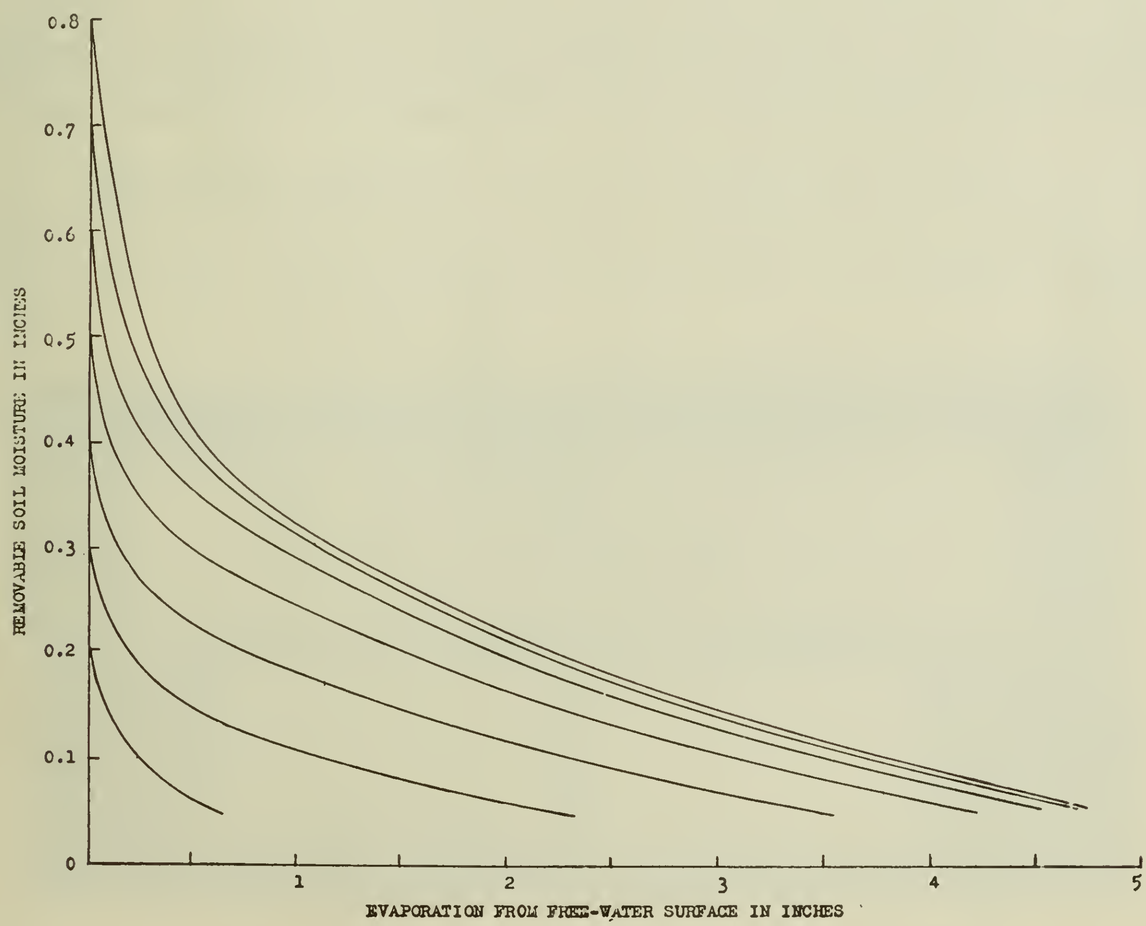


Fig. 4.—Evaporation curves for rainfall of 0·2 inch.

surface. The upper curve in Fig. 4 gives the moisture loss from summer-fallow soil in the Swift Current area when average evaporation conditions follow a heavy rainfall. A somewhat different curve would be expected for districts where the moisture conditions or soil texture differed appreciably from those at Swift Current. The zero of removable moisture is reached when the average moisture content in the top 4 inches is near the permanent wilting percentage.

If the rainfall is not sufficient to moisten the top 4 or 5 inches of soil to field capacity, the evaporation loss may be predicted by other curves such as shown in the lower part of Fig. 4. The various curves show the loss of moisture following a rainfall of 0·2 inch when the initial surface moisture content (including the rainfall) takes on different values ranging from 0·2 to 0·8 inch. When the surface 4-inch layer is below the field capacity following a rainfall, the loss by evaporation depends on both the amount of the recent rainfall and the total amount of moisture in the soil. Because of this, other sets of curves similar to Fig. 4 are required for rainfalls of 0·1, 0·3, 0·4 and 0·5 inch.

The top 4 or 5 inches of soil must be moistened to above the field capacity before further rainfall will penetrate deep enough to escape evaporation. The curves show that a loam soil above field capacity will lose approximately 0·8 inch of water by evaporation alone. It follows, therefore, that the surface must contain 0·8 inch of removable moisture before any additional rainfall will be conserved. After a long dry period a single rainfall must exceed 0·8 inch before any is safely stored. If the surface already contains 0·3 inch of water, any rainfall in excess of 0·5 inch will be conserved. When the weather is cool and damp, the surface may be kept near the field capacity by frequent showers and precipitation as light as 0·1 inch may penetrate below the evaporation zone.

As the 25-year average free-water evaporation in June is 5·8 inch, the curves in Fig. 4 show the moisture loss for about 26 days in June following a rainfall of 0·2 inch. When further rainfall occurs, the procedure of estimating evaporation is to add the amount of the rainfall to the current moisture content of the surface soil and then to choose the appropriate evaporation curve to

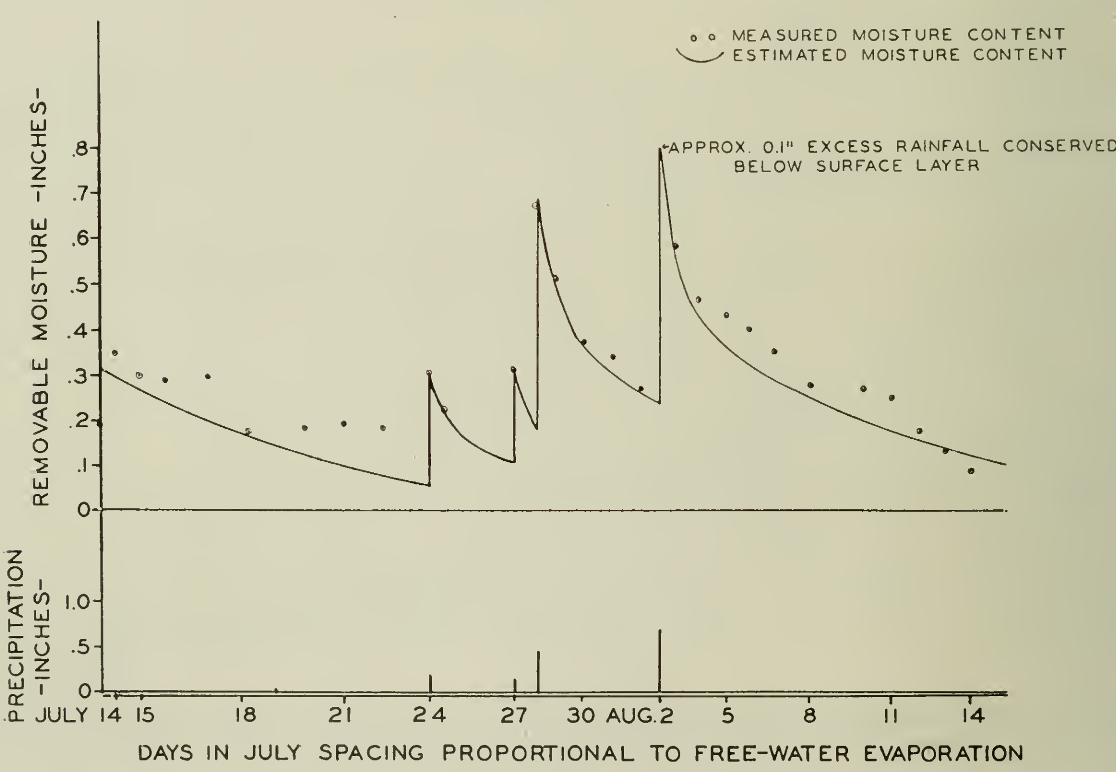


Fig. 5.—Measured and estimated moisture conservation.

find the subsequent loss. This usually involves plotting a continuous graph of the removable moisture throughout the season. When the surface moisture exceeds 0·8 inch, the excess is recorded as conserved. In making the estimate, rainfall and conserved moisture are entered in units no smaller than 0·1 inch.

Analysis of the rainfall data obtained at Swift Current since 1922 shows that much of the summer precipitation is lost in a futile wetting and drying of the surface soil with little permanent storage. The estimated moisture conservation in summerfallowed tanks and field plots from May to October for each year since 1922 was in satisfactory agreement with the measured values (42). The measured and estimated moisture content of the top 4 inches of soil in a summerfallowed plot for the period July 14 to August 14, 1941, are shown in Fig. 5. It is important that the prediction of surface moisture be accurate since the estimate of conservation for the whole season is based upon it.

The data in Table 5 show the estimated loss of moisture from weed-free summerfallow land at Swift Current after 1, 2, 5 and 10 days of average evaporation in June following precipitation of 0·2, 0·3, 0·5 and 0·75 inch. It was assumed that 8-10 days of dry weather preceded the rainfall in each case.

TABLE 5.—LOSS OF MOISTURE BY EVAPORATION FROM FALLOWED FIELDS

Amount of precipitation	Total evaporation loss after given number of days			
	1	2	5	10
inches	inches	inches	inches	inches
0·2	0·12	0·16	0·22	0·28
0·3	0·17	0·22	0·29	0·36
0·5	0·22	0·31	0·42	0·51
0·75	0·25	0·35	0·47	0·58

A tracing guide or slide rule that was developed to speed up the process of estimating stored moisture is shown in Fig. 6. The free-water scale was converted to days by assuming that the daily evaporation in any one month was equal to the daily longtime average for that month. The estimates obtained, using the rule, are nearly the same as obtained by the more detailed method.

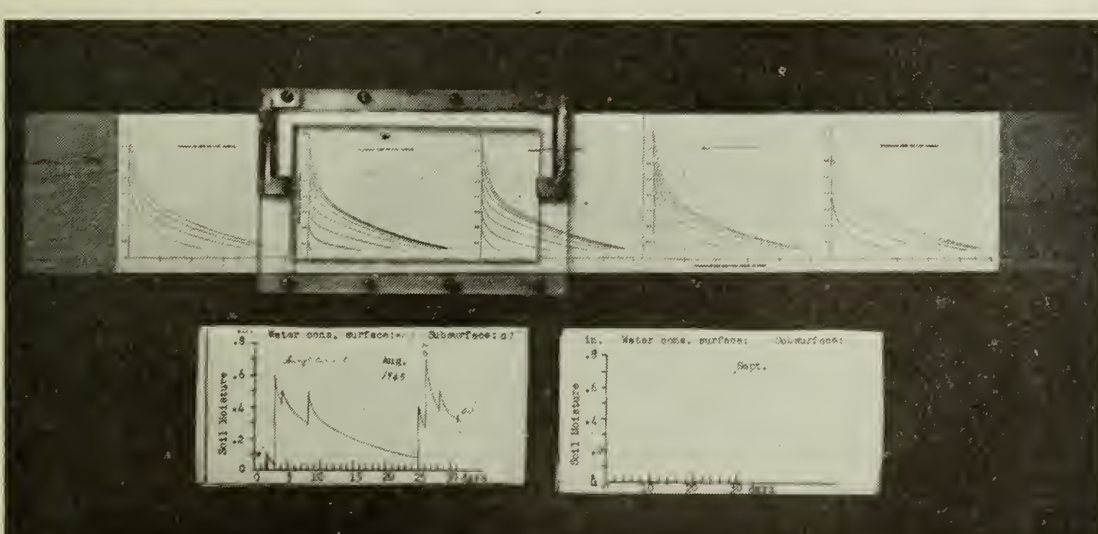


Fig. 6.—Tracing guide for estimating conservation of moisture from free-water evaporation.

The time required for a 6 months' estimate is about 30 minutes. Work is continuing in testing the method on different soil types and under different moisture conditions.

Field experiments have shown that the cultural treatment has little effect on the amount of moisture conserved in summerfallow provided weed growth is controlled to the same extent. The data in Table 6 show the average field

TABLE 6.—THE CONSERVATION OF MOISTURE UNDER DIFFERENT FALLOW TREATMENTS IN THE FIELD AND BY STANDARD FALLOW IN TANKS

Average of 4 years*

Cultural treatments	Precipitation conserved						Total conserved
	Aug. to April		May to Oct.		Nov. to April		
	per cent	inches	per cent	inches	per cent	inches	inches
One-way disk and cultivated	36·3	2·53	18·2	1·36	18·9	0·74	4·63
Cultivate only	36·3	2·53	13·3	0·99	12·5	0·49	4·01
Ploughed in June and cultivated	37·3	2·60	10·0	0·75	24·5	0·96	4·31
Surface worked and ploughed in July	45·5	3·17	11·8	0·88	5·6	0·22	4·27
One-way disk only	37·3	2·60	11·0	0·82	26·0	1·02	4·44
Average of field treatments	38·6	2·69	12·9	0·96	17·3	0·68	4·33
Conservation in standard fallow tanks for the same period	30·1	1·83	20·5	2·09	20·7	0·90	4·82

* The moisture conserved in the field was measured to a depth of 4 feet. When the precipitation was high some moisture penetrated below the 4-foot depth.

results for 4 years, as compared with moisture conservation in tank experiments for the same period. Approximately the same amount of moisture was conserved irrespective of the cultural treatment, the differences being attributed more to soil variability than to efficiency in conservation. During years of heavy precipitation the moisture would penetrate beyond the 4-foot depth recorded in these experiments.

During the August to April period the conservation in the field was 2·69 inches of water as compared with 1·83 inches in the tanks. This difference is attributed to the snow held by the long stubble and weeds in the field. The tanks were relatively bare during the winter for there were no weeds present and the stubble was only 1 or 2 inches long. During the May to October period, the tanks conserved the most moisture for they were kept free from weeds, but under field conditions, there was some weed growth which reduced the moisture supply. From November to April, when the surface conditions were more or less the same in the field and tanks, the conservation of moisture was approximately the same. An ideal condition would be a long stubble to hold snow during the winter and prevention of all weed growth during the summer.

The results indicate that 4 to 5 inches was the average amount of water that was stored in this medium-textured soil. If the summerfallow contained 4 inches of water at seeding time, a seasonal rainfall of 6·5 inches would be required to produce 12 to 15 bushels of wheat. On light soils the seasonal rainfall required would be higher, and on heavy soils, lower.

Effect of Weed Growth

The growth of weeds in a field of grain or during the fallow period uses moisture that should be conserved for crop growth. Even a light infestation of weeds may cause a serious reduction in crop yield.

The effect of weed growth on the conservation of soil moisture in tanks during the summerfallow period is shown in Table 7. All weed growth was prevented after the recorded date in each case. The crop yields on the corresponding tanks for the following year are included.

TABLE 7.—EFFECT OF WEED GROWTH ON MOISTURE CONSERVATION IN SUMMER-FALLOW AND THE YIELD OF THE FOLLOWING CROP

Average of 3 years

—	Water stored in soil	Comparative yield	
		Total crop	Grain
	inches		
Weed growth prevented	5·1	100	100
First cultivation May 15	4·5	89	88
First cultivation June 15	3·6	75	78
First cultivation July 15	1·9	43	47

The results show that the longer the period of weed growth, the less the amount of moisture conserved and the smaller the crop yield. As the crops all received the same amount of seasonal precipitation, the differences in yield were due to the difference in conserved moisture. These reductions were caused by a fairly light infestation of weeds. Weed growth following the first cultivation would be quite effective in reducing the moisture supply. The advantage of the early cultivation of summerfallow is clearly shown. Similar results would be obtained in the field.

Water Requirement of Wheat

The water requirement of a crop is the amount of water required to produce one unit of dry matter and is generally expressed as the pounds of water required to produce 1 pound of dry plant material. This includes the water transpired by the plant and lost from the soil by evaporation. The amount of water will vary depending on the conditions under which the plant was grown, for such factors as soil fertility, humidity, precipitation, and wind velocity all have some effect on the water requirement.

Some of the rotations started in 1922 have been continued until the present time on the same series of tanks. These include, continuous wheat, fallow-wheat, and fallow-wheat-wheat. Data for a shorter period are available for a 4-year rotation which included a fallow period every fourth year. The tank crops were dependent on natural precipitation for moisture, thus being similar to field crops. The weight of the tanks at harvest time showed that the crop generally used all the available moisture irrespective of the crop sequence or seasonal rainfall. Soil samples collected in the field have also shown that the crop had exhausted the available moisture to the depth of root penetration at harvest time. During some dry years the crop was rushed to maturity before the soil was dried much below three feet in depth.

The data in Table 8 show the yield and water used by wheat crops on summerfallow land. The precipitation plus the water taken from the soil equals the total water used by the crop and lost by evaporation from the soil. The data show that wheat had approximately the same water requirement irrespective of the number of years intervening between fallow periods, the yields being approximately the same. The yields obtained were somewhat higher than under field conditions which is attributed to a uniform stand of uniform plants, absence of weeds and no loss at harvest. The high yields obtained in 1942 show that these soils are quite productive when moisture conditions are favourable. Owing to a complete crop failure in 1937, the data for this year were omitted when computing the averages. The relationship between high yield and high total moisture is shown very clearly by the data.

TABLE 8.—YIELDS OF WHEAT ON SUMMERFALLOW LAND AND WATER USED BY THE CROP

(Tank experiments)

Year	Precipitation seed time to harvest	Water from soil			Yield per acre			Water used per pound total crop		
		2-year rotation[1]	3-year rotation[1]	4-year rotation[1]	2-year rotation	3-year rotation	4-year rotation	2-year rotation	3-year rotation	4-year rotation
	inches	inches	inches	inches	bu.	bu.	bu.	inches	inches	inches
1923	14·02	3·12	3·96	3·97	43·0	49·5	46·7	585	526	541
1924	7·73	6·79	6·10	5·20	36·9	46·9	47·3	484	452	416
1925	3·65	8·52	7·98	8·16	34·6	32·8	29·1	471	482	502
1926	6·00	9·73	8·24	5·18	54·0	44·9	30·9	396	409	456
1927	7·48	8·40	9·03	9·97	62·7	61·4	64·9	408	419	420
1928	7·63	10·36	9·77	9·10	64·8	59·9	61·7	331	364	322
1929	6·12	5·18	5·61	7·81	22·5	23·9	24·1	545	550	574
1930	4·83	5·65	4·55	4·47	28·2	25·5	21·8	434	443	466
1931	4·89	3·10	3·89	....	17·1	20·1	....	694	691	....
1932	7·89	3·89	3·77	....	27·3	25·9	....	563	585	....
1933	4·31	6·24	6·86	....	28·0	29·1	....	595	574	....
1934	5·89	5·34	5·42	....	28·3	20·2	....	503	698	....
1935	8·16	3·57	3·73	....	31·8	32·4	....	478	520	....
1936	2·65	5·02	4·40	....	8·1	10·2	....	813	773	....
1937	2·90[2]	....	....	....	....	....	....	....	....	....
1938	3·38	5·45	6·04	....	20·8	25·5	....	483	459	....
1939	11·30	5·80	5·90	....	50·6	52·5	....	544	501	....
1940	5·26	8·46	8·10	....	38·1	12·5	....	487	612	....
1941	4·24	3·30	1·76	....	3·3	0·2	....	1,633	1,696	....
1942	10·32	2·01	2·58	....	59·9	72·1	....	328	287	....
1943	4·32	9·85	9·73	....	33·4	32·0	....	569	587	....
1944	10·19	4·40	3·14	....	47·8	48·4	....	532	501	....
1945	2·97	5·60	5·32	....	16·5	17·2	....	780	755	....
1946	5·58	3·49	3·06	....	11·1	12·5	....	1,257	1,100	....
Average 1923-1930	7·18	7·22	6·90	6·73	43·3	43·1	40·8	457	456	462
Average 1923-1946	6·47	5·79	5·61	....	33·4	32·9	....	605	608	....

[1] 2-year rotation, fallow-wheat. 3-year rotation, fallow-wheat-wheat. 4-year rotation, fallow-wheat-wheat-oats.

[2] 1937, crop failure, not included in average.

During 11 of the 23 years the crops secured more water from the soil than from precipitation during the growing season. The majority of these years were seasons of relatively low rainfall which emphasizes the importance of stored moisture during a drought period.

The data in Table 9 showing the yield and water requirement of wheat on stubble land provide a sharp contrast to the data pertaining to fallow crops.

An examination of Tables 8 and 9 shows that the water requirement usually varies inversely as the amount of water used by the crop. A certain quantity of water is required before any grain is produced and the proportion of this "unproductive" water is greatest when the total use is low. This is easily demonstrated by plotting the yields of wheat grown in summerfallow tanks against the total water used. The yield is nil until the water used exceeds about 4·9 inches, then it increases almost linearly at the rate of 4·7 bushels for each additional inch of water. The yield may be expressed by the equation $y = 4 \cdot 7\ (M - 4 \cdot 9)$ when y is the yield in bushels per acre and M the total water used in inches. It is the ratio $\frac{M - 4 \cdot 9}{y}$ and not the water requirement $\frac{M}{y}$ that remains constant when different amounts of water are used. The water requirement is most useful as a rough measure of the efficiency in the use of water when different crops or treatments are compared under identical moisture conditions.

TABLE 9.—YIELDS OF WHEAT ON STUBBLE LAND AND WATER USED BY THE CROP

(Tank experiments)

Year	Precipitation seed time to harvest	Water from soil			Yield per acre			Water used per pound total crop		
		Wheat cont.	3-year rotation	4-year rotation	Wheat cont.	3-year rotation	4-year rotation	Wheat cont.	3-year rotation	4-year rotation
	inches	inches	inches	inches	bu.	bu.	bu.	inches	inches	inches
1924	7·73	0·65[1]	0·04	0·27	9·7	12·4	14·6	1,085	920	856
1925	3·65	4·94	4·40	4·04	19·0	16·2	14·0	551	597	596
1926	6·00	2·32	2·15	1·92	16·3	14·7	13·3	626	719	770
1927	7·48	5·42	5·22	5·50	42·0	44·0	37·6	475	476	497
1928	7·54	1·53	1·02	1·45	18·9	21·7	24·3	495	452	442
1929	5·70	0·75	0·47	0·16	8·5	8·4	6·8	813	795	845
1930	4·80	1·80	1·65	1·77	11·5	11·4	10·0	663	607	705
1931	4·89	0·08[1]	0·00	....	5·1	5·4	....	1,342	1,169	....
1932	9·23	1·06	0·55	....	10·8	8·9	....	784	923	....
1933	4·31	3·14	2·67	....	13·6	11·0	....	884	948	....
1934	5·89	1·85	1·96	....	11·2	11·3	....	784	732	....
1935	7·57	[1]	0·31	....	[1]	13·9	....	[1]	759	....
1936	2·65	0·79	1·34	....	2·6	2·4	....	1,099	1,456	....
1937	2·90[1]	....	....	....	....	....	....	....	....	....
1938	3·38	5·85	5·65	....	23·9	20·9	....	489	480	....
1939	11·28	3·82	4·02	....	45·8	46·7	....	519	520	....
1940	5·07	1·96	1·96	....	7·3	7·8	....	937	935	....
1941	4·24	0·83	1·65	....	0·1	0·6	....	2,100[2]	2,382[2]	....
1942	10·32	0·49	0·77	....	48·2	53·3	....	391	473	....
1943	4·32	4·55	4·43	....	6·6	5·1	....	....	1,817[2]	....
1944	10·19	3·73	1·92	....	41·1	34·9	....	609	648	....
1945	2·00	2·12	2·92	....	4·4	5·8	....	1,545	1,470	....
1946	5·58	2·49	2·47	....	10·4	10·9	....	1,215	1,047	....
Average 1924-1930	6·13	2·30	2·14	2·16	18·0	18·4	17·2	673	652	673
Average 1924-1946	6·08	2·32	2·16	....	17·0	16·7	....	806	806	....

[1] Crop damaged or failed, not included in average.

[2] Not included in average.

The greater water requirement of stubble crops as compared with summer-fallow crops (Tables 8 and 9) is explained almost entirely by the difference in the amount of water used. The average relationship between yield and water use was nearly the same for the two crops. The stubble crops were more dependent on the seasonal rainfall, obtaining only 26·9 per cent of the total water used from that stored in the soil, while the crops on fallow obtained 46·8 per cent from stored moisture. The stubble crops had access to an average of 8·32 inches of water as compared with 12·7 inches for the fallow crops. This lower moisture supply resulted in a difference in yield of 16·2 bushels.

The water requirement of the 1941 stubble crop was omitted when computing the averages, owing to the very small crop harvested. During years of severe drought, the water requirement is increased to a figure several times as large as that for an average crop. The data for the years 1941 and 1942 show very clearly the definite influence of climatic conditions on water requirement.

Analysis of data from the 2-year rotation showed that the increase in yield per inch of precipitation was over 1·5 times as large as the increase per inch of stored water used. This was unexpected since some of the rainfall must be lost by surface evaporation from the soil. A probable explanation is that the seasonal rainfall contributed to a number of other factors such as reduced evaporation, good seed germination, availability of plant food, etc., which, in turn, improve the yields. The partial correlation of yield with free-water evaporation, independent of the amount of water used, was below the 0·05 level of significance.

29171—3

TABLE 10.—YIELD AND WATER REQUIREMENT OF WHEAT IN FIELD EXPERIMENTS

Location	Soil type	Number of crops	Crop	Moisture used by crop			Yield
				From soil	Rainfall	Total	
				inches	inches	inches	
Valjean	Ch. S. L.	7	Fallow wheat	4·38	6·07	10·45	14·7
Kincaid	Hr. L	7	Fallow wheat	6·15	7·57	13·72	27·0
Swift Current	Hr. L.	7	Fallow wheat	4·33	6·82	11·15	23·3
Swift Current	Hr. L.	7	Stubble wheat	1·91	6·55	8·46	16·5
Shaunavon	Hr. L.	7	Fallow wheat	5·17	6·50	11·67	20·0
Scott	W. L.	3	Fallow and stubble wheat	3·94	4·96	8·90	9·1
Tugaske	W. L.	7	Fallow wheat	4·85	8·36	13·20	24·5
Carmichael	Cy. L.	6	Fallow wheat	4·42	9·17	13·60	25·1
Fox Valley	Fx. S. L.	4	Fallow wheat	3·06	5·63	8·69	17·6
Riverhurst	Fx. S. L.	7	Fallow wheat	2·58	5·71	8·29	15·2
Radville	Tr. C. L.	3	Fallow wheat	2·29	5·37	7·65	20·4
Gravelbourg	Sc. C.	8	Fallow wheat	4·33	7·10	11·43	22·7
Shackleton	Sc. C.	5	Fallow wheat	5·12	5·28	10·40	20·8
Rosetown	R. C.	1	Fallow wheat	3·14	7·00	10·14	17·1
Regina	R. Hv. C.	4	Fallow and stubble wheat	2·46	8·49	10·95	21·0
Indian Head	Hv. C.	2	Fallow wheat	4·59	6·85	11·44	22·8
Sceptre	Sc. Hv. C.	6	Fallow wheat	4·33	7·21	11·54	28·4
Sceptre	Sc. Hv. C.	4	Stubble wheat	3·25	7·77	11·01	21·7

The data in Table 10 show the yield and water requirement of wheat grown on the substations, under the direction of the Dominion Experimental Station at Swift Current, during the years 1938-1946. The amount of water used was calculated from the seasonal rainfall and the difference in moisture content of the soil to a depth of 4 feet at seeding time and harvest. The data indicate that the crops on the heavier soils made more efficient use of the moisture than the crops on the lighter soils. Seasonal precipitation made up 63 per cent of the total water used. The yield of the individual crops is plotted against the moisture used in Fig. 7. The curve shown was the best fit obtained for the experimental data.

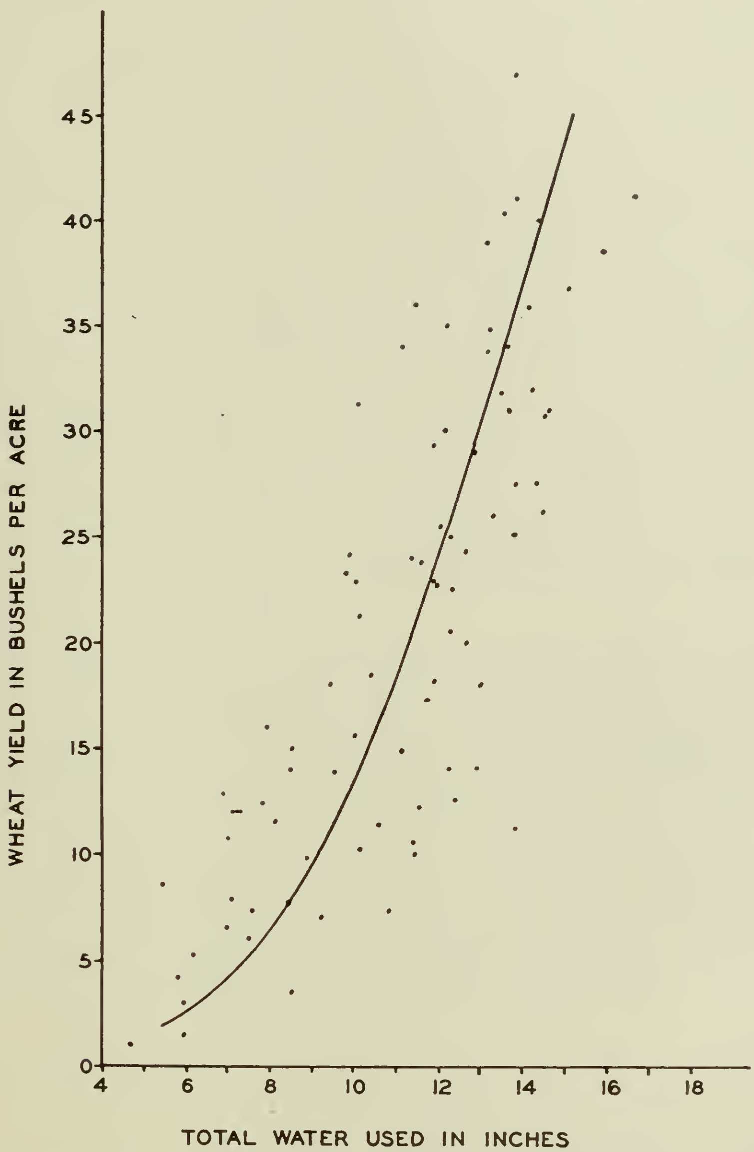


Fig. 7.—Yield and moisture requirement of wheat. Field results, 1938-1946.

Crops that used less than 10·5 inches of water generally yielded less than 14 bushels per acre. When the water used was above 10·5 there was an average increase of approximately 6·5 bushels per acre for each additional inch of water. The distribution of points in Fig. 7 shows the variations that were found, these being determined largely by the distribution of rainfall and other factors which changed the effectiveness of moisture use from season to season. As the average seasonal rainfall for the Swift Current area is 7·78 inches, there must be 3 inches or more of reserve soil moisture, or more than average seasonal rainfall to produce a crop of 14 bushels or over.

TABLE 11.—ACTUAL YIELD AND ERRORS OF ESTIMATE (BU/ACRE) AT 6 STATIONS

Location	1940		1941		1942		1944		1945		1946		Mean	
	Actual yield	Error of estimate	Actual yield	Error of estimate	Actual yield	Error of estimate	Actual yield	Error of estimate	Actual yield	Error of estimate	Actual yield	Error of estimate	Actual yield	Error of estimate
Riverhurst	11·5	0·3	1·5	− 2·3	36·1	17·6	24·0	1·7	5·3	− 1·2	12·4	2·7	15·1	3·1
Tugaske	20·5	− 4·7	14·0	−11·1	38·6	7·2	27·0	− 9·7	22·5	− 6·0	18·0	1·8	23·4	− 3·7
Gravelbourg	25·5	1·5	17·2	− 6·1	40·0	10·0	31·0	0·6	12·8	2·8	12·0	4·2	23·1	2·2
Kincaid	27·5	− 4·3	25·1	− 4·6	53·4	16·9	31·0	− 3·4	14·9	− 9·5	13·9	0·1	27·6	− 0·8
Shaunavon	35·9	4·6	12·5	−13·3	30·1	7·0	32·0	− 1·1	7·4	−14·0	15·0	1·0	22·1	− 2·6
Swift Current	18·5	− 1·0	3·5	−10·1	39·0	14·1	47·0	17·6	7·5	− 7·1	15·6	− 1·3	21·9	2·0
Mean	23·2	− 0·6	12·3	− 7·9	39·5	12·1	32·0	0·9	11·7	− 5·8	14·5	1·4	22·2	

Errors of estimate = actual yield − calculated yield.

More information about the scatter in Fig. 7 was obtained in an analysis of 6 years results at six of the substations. The variance due to differences in location and season were first subtracted from the total and the regression of yield on the use of precipitation and stored water was calculated from the remainder or error variance (40). This gives the average relationship between yield and water use when the effects of location and season are eliminated. Table 11 shows the actual yields and the differences between these and the yields estimated from the calculations described above. A comparison of the mean errors of estimate at the bottom of the table shows the relative efficiency in the use of water for different seasons. In 1941 the mean yield was 7·9 bushels per acre below the estimate whereas in 1942 it was 12·1 bushels per acre above the estimate. The efficiency does not appear to be definitely related to yield. Differences between the mean errors of estimate for any two seasons must equal 6·3 bushels per acre to reach the 0·05 level of significance. Significant differences may be interpreted to mean that some factors, other than the amount of water used, have influenced the crop during one or both of the seasons. The mean errors of estimate in the last column of Table 11 provide a similar comparison of the efficiency at different locations. The results as a whole show that the efficiency in water use may differ significantly from year to year but that the variation between the stations is likely to be small. When differences in rainfall occur in local areas in any one season, the distribution with time in all such areas is likely to follow the same general pattern but the distribution for different seasons would probably be quite different. The data in Table 11 show that the factors, which make one season more favourable for crop growth than another, must operate similarly at the different stations.

The relative effect of precipitation and stored water on the yield of wheat was compared at the six stations. When all locations and seasons were considered together the yield per inch of precipitation was about 1·7 times that obtained per inch of stored water used. This result is of the same order as that obtained from the tank data.

The Rate of Use of Water During the Season

The wheat crop in southwestern Saskatchewan is generally seeded about the first of May and harvested in August or early September. At seeding time the available moisture content of summerfallowed Haverhill loam soil usually varies from about 3·5 to 6 inches. This corresponds to 30 to 50 inches of moist soil, the moisture content being a little short of field capacity.

The curves in Fig. 8 show the changes of available moisture in the soil at three stations during the crop season of 1942. The available moisture was determined by taking soil samples to a depth of 4 feet. Three combinations of reserve moisture and seasonal rainfall are represented.

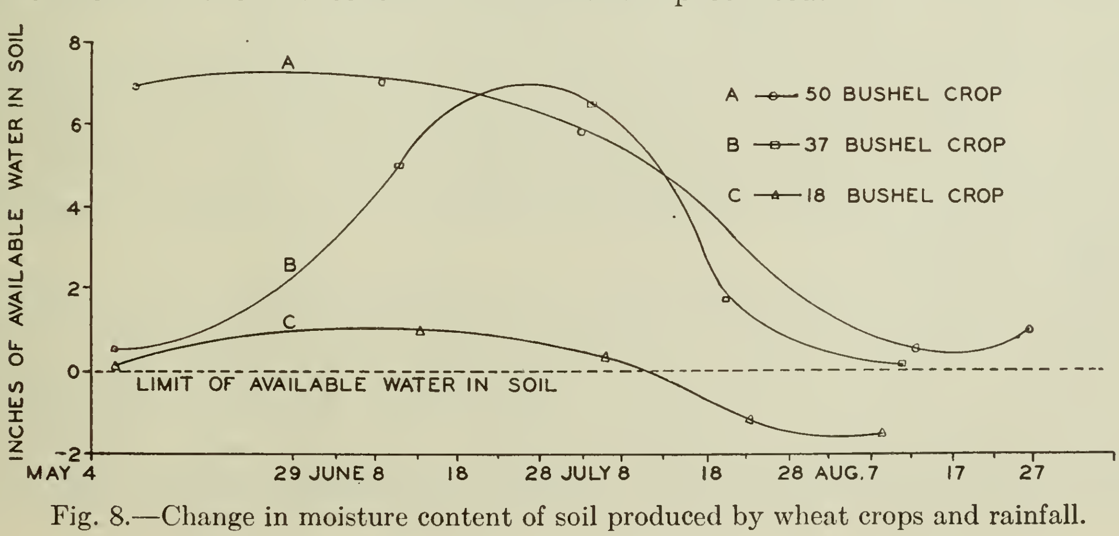


Fig. 8.—Change in moisture content of soil produced by wheat crops and rainfall.

Curve A represents a condition of high available moisture at seeding time and a good distribution of a 9-inch seasonal rainfall. The crop made a vigorous growth which was sustained throughout the season. At no time was the supply of available moisture exhausted. This crop yielded 50 bushels per acre. Curve B shows very little available moisture in the spring and a seasonal rainfall of 13 inches, the major portion of which fell during the critical period of plant growth. Growth was rather slow at first but after the June rains started there was a very rapid growth, and almost complete development of all tillers. There was sufficient moisture to meet the requirements of the crop despite the rapid use of available moisture during July. A yield of 37 bushels was obtained. Curve C represents a low amount of available moisture and a good distribution of the seasonal rainfall of 10 inches. There was not sufficient moisture at any time to cause a heavy growth of straw or appreciable tillering. By the time the supply of available moisture was exhausted the crop was past the critical period and sufficiently advanced to prevent serious damage, giving a yield of 18 bushels per acre. The year 1942 was very favourable for crop growth from the standpoint of both quantity and distribution of rainfall, otherwise crops B and C would have failed.

The curves in Fig. 9 show the rate of use of water by the same crops as listed in Fig. 8. These data represent the sum of the precipitation and the reduction in soil moisture at the dates listed. The use of water was rather slow during the early part of the season, amounting to only 4 inches by June 18 for crops A and C, and less for B. After this date there was a very rapid increase in the use of water due to the increased growth of crop. During July, which was the period of heading and filling, the demand for water reached a maximum.

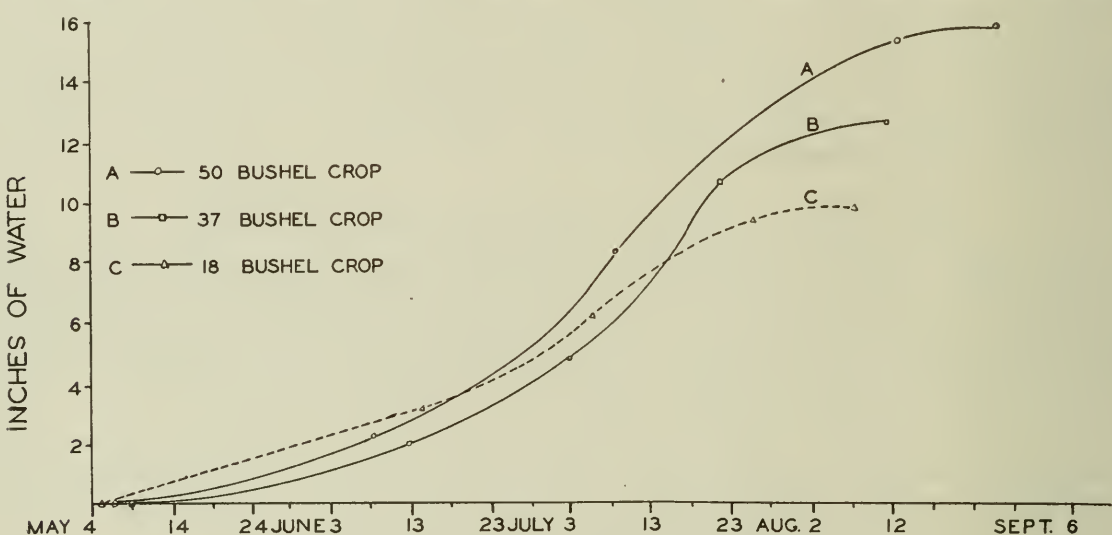


Fig. 9.—The rate of use of moisture by wheat crops.

Crop B used 5 inches of water from July 3 to July 19, an average of 0·32 inch per day. During the critical period of heading and filling, a heavy crop may use approximately 0·5 inch of water during a hot windy day. The high rate of transpiration of a rapidly growing crop explains why a few days with hot dry winds may cause a serious reduction in crop yield, if the supply of available moisture is exhausted.

The demand for water decreased very rapidly when the crops began to ripen as shown by the levelling off of the curves toward the end of July. Rains at this period may have little or no beneficial effect except on late crops. The data bring out the importance of the distribution of the rainfall, especially in years when the reserve of available moisture is low. The proper distribution of a low seasonal rainfall may produce a larger crop than a higher rainfall that does not come at the right time. Adequate supplies of moisture must be available during the heading and filling stage maximum for production.

An analysis of the rate of use of water by wheat grown in tanks gave some additional information on the effectiveness of the moisture used at different stages of crop growth. The season was divided into six 15-day periods from May 17 to August 14, inclusive, and partial correlations were found between yield and the ratio of moisture used to free-water evaporation for each period.

The highest correlation found was between the yield and the moisture used in the first 15 days in July, when, in most years, the crop heads out and starts to fill. In dry districts, the available moisture supply is frequently exhausted during this period. The second highest correlation obtained was for the filling period in the latter part of July. The correlation reached the 0·05 level of significance for these two periods only. The third highest correlation between yield and moisture use was during the period May 17-31. A moist surface condition is required in May for good germination and early development of the crop. The only other correlation of appreciable size was obtained for the period June 16-30. That this correlation was low may seem surprising because the latter part of June is frequently considered to be the critical period for the wheat crop. A high use of moisture during this period, however, does not ensure high yields. As Cole and Mathews (23) pointed out in reporting on the use of water by spring wheat in the Great Plains of the United States, "The final yield of the wheat crop is determined more by the length of time it uses water rapidly than by the rate of use".

A low negative correlation obtained between yield and the quantity of water used for the first half of June is of interest since this is the period when tillering takes place and it is sometimes observed that an excessive growth at this time may reduce the ultimate yield in dry years. An example of this was in 1941, when in many districts, a high surface moisture content resulted in a large number of tillers. Since most of the crops suffered from drought early in July, only about half of the tillers produced mature heads and the grain sample was generally poor.

Effect of Additional Moisture on Yield of Wheat

The dependence of crop yield on the moisture supply has been shown by the previous experiments. In practically every case the highest yields were obtained when moisture conditions were the most favourable. The effect of an additional supply of moisture on the yield of wheat grown in tanks has been determined by supplementing the seasonal rainfall. No definite amount of water was added to the tanks but the supply of available moisture was kept at a high level at all times and at all depths. The data in Table 12 show the effect of additional moisture on the yield of wheat on summerfallow and stubble. The average yield for 20 years on summerfallow with additional moisture was 57·6 bushels as compared with 32·4 for rainfall alone. The stubble crop for the same period, where wheat was grown every year in the same tanks, produced at the rate of 17·0 bushels per acre with rainfall only as compared with 43·6 bushels when additional moisture was provided.

TABLE 12.—EFFECT OF ADDITIONAL MOISTURE ON YIELD OF WHEAT

20-year average

—	Additional moisture	Rainfall only
	bu.	bu.
Wheat on summerfallow	57·6	32·4
Continuous wheat	43·6	17·0

Another series of tanks, filled with soil from a field that had been in cultivation for the preceding 20 years, produced an average yield of 35·9 bushels under

continuous cropping for the 20-year period when supplied with additional moisture.

The average yield for the last 5 years for each of the different series has been equal to the average yield for the first 5 years. These yields were all obtained without the use of fertilizers, thus indicating the high productivity of these soils when adequate moisture is available.

Effect of Weeds on Yield of Wheat

A previous discussion emphasized the effect of weed growth during the summerfallow period on the conservation of moisture. Likewise, weed growth in a grain field reduces the supply of available moisture thus competing with the grain. Even a light infestation may cause an appreciable reduction in yield and also interfere with harvesting operations. A series of experiments were conducted to determine the reduction in crop yield caused by different kinds of weeds. Seeds of four noxious weeds were planted in the tanks and allowed to grow with the wheat. No attempt was made to control the degree of infestation which varied from year to year. Tanks without weeds were included for comparison. The average results for a 10-year period are recorded in Table 13.

TABLE 13.—COMPARATIVE EFFECT OF WEEDS ON YIELD OF WHEAT

Average of 10 years

Wheat and	Total water used	Water to produce 1 lb. dry material		Comparative weight		Proportion threshed grain to total crop
		Total crop	Grain	Total crop	Grain	
	inches	lb.	lb.			per cent
No weeds	11·2	558	1,590	100	100	36·3
Russian thistle	10·0	521	4,494	118	73	22·4
Stinkweed	9·9	658	2,039	82	75	33·5
Tumbling mustard	10·8	670	3,254	93	75	29·5
Wild oats	10·5	650	2,687	84	57	24·8

The data show that all the weeds caused an appreciable reduction in crop yield. The wheat and Russian thistle mixture was the most efficient in the use of water, producing the largest amount of dry plant material, and also the lowest proportion of threshed grain. Russian thistle has the lowest water requirement of any of the plants investigated, which accounts for its rapid growth during periods of drought. It is the most serious competitor during years of low rainfall and causes the maximum reduction in crop yield under these conditions. The other weeds are not as efficient in the use of moisture and make their most vigorous growth during periods of more ample moisture supply. Weeds of any kind are a serious menace to maximum crop production.

Effect of Shelterbelts

Shelterbelts affect soil moisture in three ways. The roots of the shrubs and trees reduce the soil moisture for a distance of 5 to 25 feet on either side depending on the height of the trees. During the winter, snow accumulates in and near the shelterbelt and thus increases the soil moisture when the snow melts. The extent of snow accumulation is determined by the snow fall, direction and severity of winds, and the height and density of the shelterbelt. A shelterbelt also decreases the wind velocity which causes a reduction in the evaporation from the soil and transpiration from the crop.

A dense belt of trees 25 feet in height will cause a reduction in wind velocity and evaporation to a distance of over 400 feet to leeward. The reduction will

be greatest near the shelterbelt, with a velocity at 200 feet approximately 50 per cent of that in the open. A 4-row belt of caragana and maple 10 to 13 feet high will reduce the wind velocity for a distance of 100 to 200 feet to leeward. The increase in velocity, with distance to leeward, is so gradual and the nature of wind so complex, that no definite limit of influence can be determined.

Soil samples collected in the vicinity of shelterbelts in the spring have shown an increase in soil moisture for a distance of 25 to 150 feet. The area of increased soil moisture corresponds roughly to the area covered by snow drifts, though on sloping land, the snow water may spread over a large area.

The average yields obtained from crops adjacent to a number of shelterbelts in the Conquest and Swift Current areas for the years 1938 to 1940 are recorded in Table 14. Yields are reported for increasing distances to leeward until a point was reached which was representative of the field as a whole. The distance varied with the height of the shelterbelt; low, medium, and high shelterbelts showing increases for 50, 150, and 200 feet, respectively.

TABLE 14.—EFFECT OF SHELTERBELTS ON YIELD OF WHEAT

Distance from shelterbelt	Low shelterbelt 5′ to 8′	Medium shelterbelt 8′ to 15′	High shelterbelt 15′ to 25′
Feet	bushels	bushels	bushels
25	29·2	33·4	28·3
50	22·0	29·6	34·6
75	15·3	28·0	31·9
100	14·5	25·6	30·8
150	14·5	26·7	29·8
200	...	21·2	28·8
250	...	21·0	26·1
300	...	...	26·2

The ratio of grain to straw, and weight per bushel were generally increased in the area of belt influence in years of low rainfall and reduced in years of high rainfall.

Crop Forecasting

The previous discussions have dealt with the importance of soil moisture and seasonal precipitation on crop production in the prairie regions. An examination of the data in Fig. 2 shows a wide variation in annual and seasonal precipitation, and that there are many years of low rainfall when crop growth will be restricted. At present there is no way of predicting the rainfall or its distribution with any degree of accuracy.

The results in Table 8 show that crops on summerfallow may secure 50 per cent or more of the water used, from the reserve moisture stored in the soil at seeding time. This reserve represents the accumulation during the period between crops, part of which may be the result of rain that fell 18 to 21 months previously. Tank results, Table 4, have shown that the average conservation of moisture in summerfallow over a period of 23 years amounted to 5·33 inches or 26·8 per cent of the precipitation. Under field conditions, Table 6, the average conservation for 4 years was 4·33 inches.

The data in Fig. 7 show that, under field conditions, 10·5 inches of water produced from 13 to 15 bushels of grain. When the total water used was over 10·5 inches there was an increase of approximately 6·5 bushels for each additional inch of water.

On this basis a reserve of 4 inches of water in the soil at seeding time with an average seasonal rainfall of 7·78 inches should produce 20 to 25 bushels of wheat. However, in only 22 of the 62 years reported in Fig. 2 was the seasonal rainfall equal to or above the average of 7·78 inches, thus the chances of securing average or above average seasonal rainfall are 1 to 2·8 or about every third year. The information available points to the reserve moisture at seeding time as being the starting point for predicting crop yield, the crop prospects varying directly with the content of reserve moisture.

Soil Temperature

The mean soil and air temperatures at Swift Current for May-September, 1937 to 1941, are given in Table 15. The soil data were obtained with a recording thermograph, the bulb of which was buried to a depth of 4 inches in a loam soil. The soil surface was uncultivated except for an occasional hoeing to kill weeds. The average monthly soil temperatures do not vary greatly from year to year.

TABLE 15.—MEAN SOIL AND AIR TEMPERATURES

Year	May		June		July		August		September	
	Soil	Air	Soil	Air	Soil	Air	Soil	Air	Soil	Air
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1937	55	54	64	63	74	70	68	65	....	54
1938	51	50	65	62	74	68	66	62	63	63
1939	53	54	55	54	73	66	70	64	58	54
1940	57	57	63	60	71	67	70	66	61	59
1941	53	54	66	63	72	70	66	65	49	49

The effect of differences in soil moisture must be small since the temperatures in 1937 and 1939 were nearly the same although 1937 was one of the driest years on record and 1939 one of the wettest. The degree of influence is shown best by comparing the average soil and air temperatures for July and August in these two years. The higher surface moisture content in 1939 resulted in greater heat conductivity and higher soil temperatures relative to the air temperature than in 1937.

During the summer months the daily soil temperature at a depth of 4 inches had a minimum value at about 6:30 a.m. and a maximum about 5:30 p.m. There was a time lag of over 3 hours between the occurrence of the maximum at the surface and at the 4-inch level. The variation of soil temperature with time may be represented approximately by a sine curve, the daily range at the 4-inch depth during June and July being about 15°F. At the same time, heat was conducted downward by a mean temperature gradient of 0·5 to 0·75°F. per inch.

If continuous temperature records are obtained at one depth, the approximate temperatures at other depths can be calculated as shown by Keen (31). The effect of moisture content and cultivation on the conductivity of the soil must be known. The daily range of soil temperature is a maximum at the surface and decreases exponentially with depth until it becomes negligible beyond 15 or 20 inches. The temperatures at depths of 0·5 inch, 1 inch, 4 inches and 8 inches were measured at Swift Current with electrical resistance thermometers. On clear July days, the daily range at the 0·5 inch depth in firm, moderately moist loam soil was 2·5 times that at 4 inches. The ratio increased with cultivation and drying, the surface soil becoming a better insulator. When mulched

to a depth of 2 inches, the range at 0·5 inch was 3 times that at 4 inches and it increased to 4·5 times during 10 days of dry weather in late July. The average temperature at a depth of 3 inches in a soil that was mulched after each rain was 1 to 2°F. lower than that of unmulched soil. The daily range at 8 inches in moist fallow soil was 0·45 times that at 4 inches. Below 4 inches in fallow the ratio is fairly constant throughout the season. The diffusivity (conductivity ÷ specific heat capacity) for the layer, 0·5 inch to 4 inch, varied from 0·003 to 0·001 (C.G.S. units) as the soil dried out. The diffusivity between the 4-inch and the 8-inch depth was approximately 0·005. The temperatures within an inch or two of the surface are difficult to predict because of the variability in soil moisture and porosity.

Soil temperatures at depths of 1 foot, 2 feet and 4 feet were measured at various intervals during the years 1937 to 1944. The thermometers, which were supplied by the Dominion Meteorological Service, were the ordinary mercury-in-glass type with their bulbs imbedded in paraffin wax and the whole covered by a large glass tube. The paraffin insulation permitted the thermometers to be taken out of the ground without appreciable change in temperature reading. Temperatures were measured in two plots on which grain was grown in two-year rotations of summerfallow: wheat. One plot was cropped and one summerfallowed each year so that the temperatures in the two treatments could be observed under the same seasonal weather conditions. The effect of snow coverage could be studied in the winter since the cropped plot held more snow than the fallow.

The curves in Fig. 10 show the soil temperatures from Sept. 15, 1937, to Oct. 15, 1938, at depths of 1 foot and 4 feet in the 1938 fallow plot. A three-day moving mean of the air temperature is included in the figure. The temperatures at the 1-foot and 2-foot depths changed rapidly from day to day and the number of observations was insufficient to obtain all the detail. The temperature at one foot in depth was usually at a maximum in July and a minimum in February. The zero gradient or overturn occurred about the end of September and the end of March. From April to September the temperatures at the 1 and 2 foot

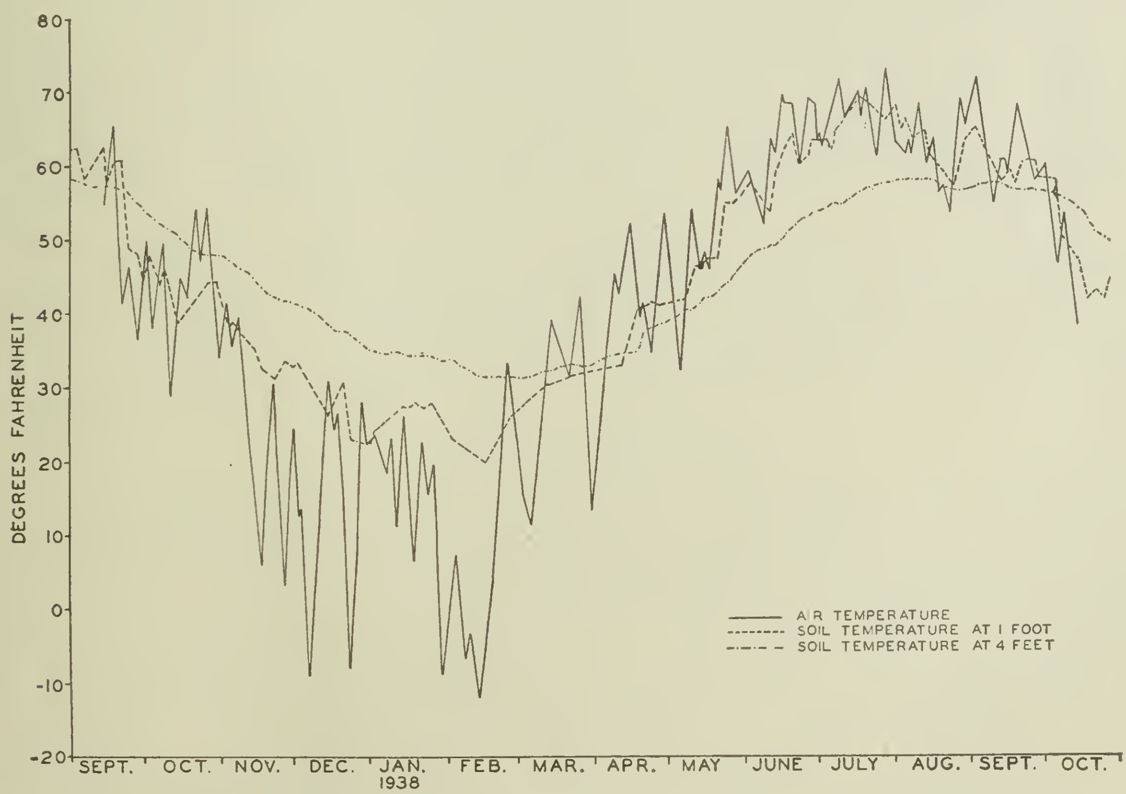


Fig. 10.—Soil temperature at depths of 1 foot and 4 feet. Sept. 1937—Oct. 1938.

depths were higher than at 4 feet and from October to March they were lower. Neglecting minor variations the annual range in 1938 was 43°F., 36°F., and 26°F. at the 1-foot, 2-foot and 4-foot levels, respectively. The diffusivity

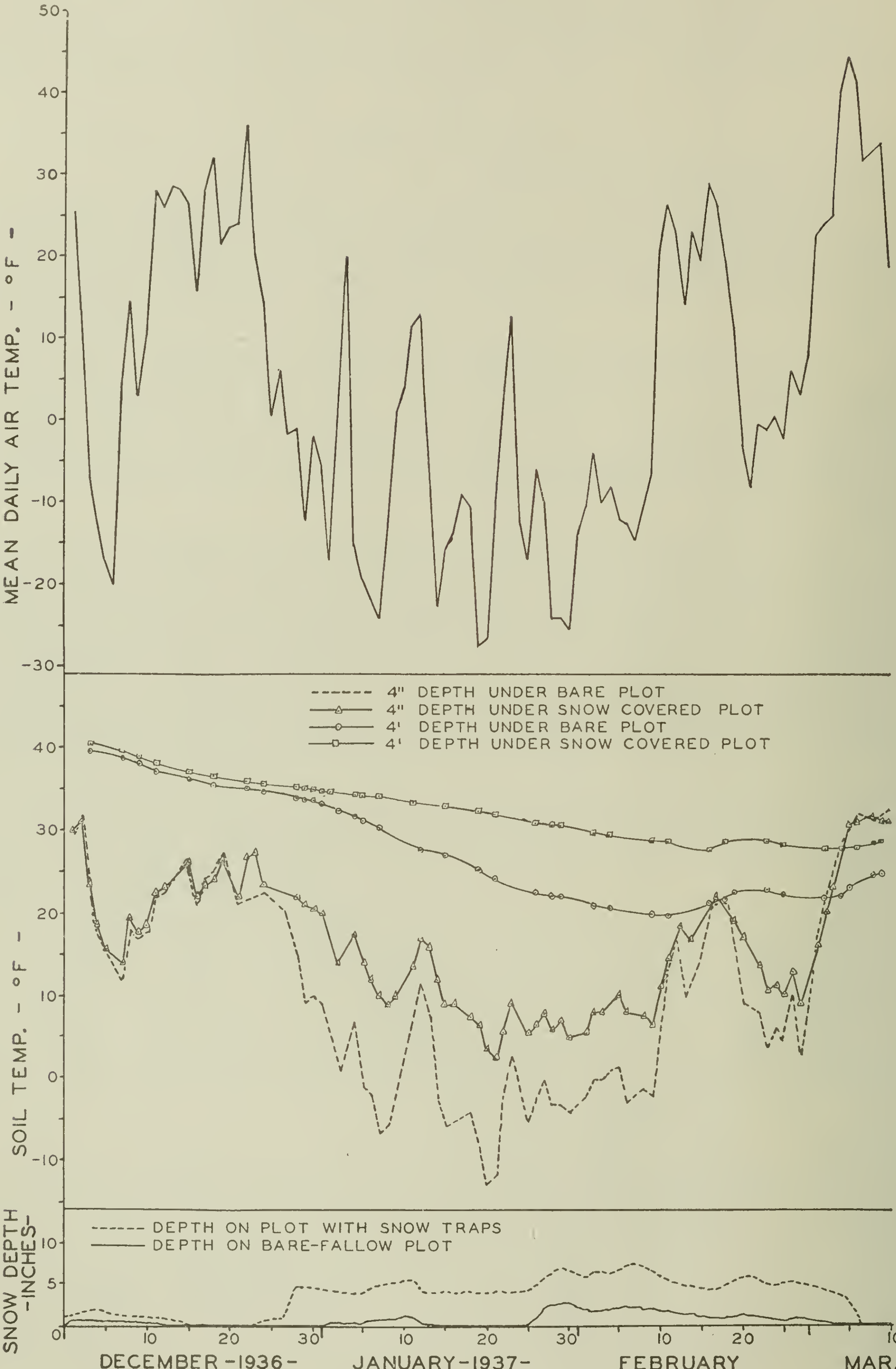


Fig. 11.—Soil temperatures at depths of 4 inches and 4 feet in bare and snow covered plots. Winter 1936-37.

calculated from these data was 0·0033. This result checks with the value of 0·0036 obtained by Callendar and McLeod at Montreal (5). The diffusivity obtained for 1937 was 0·002 and for 1939 it was 0·005. The latter values are probably near the lower and upper limits for this soil, since in 1937 the moisture content was near the wilting point and in 1939 it was approaching field capacity.

The only marked difference in soil temperature between the cropped and fallowed plots was due to differences in snow cover. Soil temperatures at depths of 4 inches and 4 feet in bare and snow-covered plots during the winter 1936-1937 are shown in Fig. 11. The average daily air temperatures and the depths of snow cover are also shown. For over a month the temperature of the fallow plot at 4-inch depth was 10°F. colder than the snow-covered plot. The moisture content of the soil was about the same in the two plots. The insulating effect was large in 1936-37 because the snowfall was relatively light and the fallow remained almost bare. During most winters some drifts accumulated on fallow and although the coverage on the stubble was also greater the contrast was reduced. As little as one inch of snow was effective in protecting the soil from extremes of temperatures in the spring and fall. Frequently the protection is magnified by the latent heat stabilizing the temperature near 32°F. When the conduction of heat at the soil surface is slow, as is the case under a snow cover, the heat that passes in or out results in the thawing or freezing of more moist soil rather than in change of temperature.

For optimum conservation of moisture from snowfall the snow must melt at a moderate rate in the spring, and the surface soil must be unfrozen when the thaw occurs. Frequently the spring break-up comes in early March, when, during a few days of clear skies and warm southwest winds, the daily maximum air temperature may increase from about 20°F. to over 40°F. Under such conditions, most of the snow disappears in 3 or 4 days and some run-off is inevitable even following dry years when the soil is in the most favourable condition to absorb water.

The moisture content of the soil and the amount of snow coverage determine the amount of "frost" in the ground. Once rapid thawing occurs the snow is no longer a good insulator and usually within 2 to 5 days the temperature of the soil rises almost to 32°F. If the soil is dry, it will absorb water to a depth of 4 to 8 inches by the time the rapid run-off commences. Moist soils, on the other hand, remain frozen for some days and frequently the peak of the run-off is passed while the soil temperature at the 1-foot level is still about 27°F. The process of thawing is hastened by the accumulation of water in furrows and depressions. Fortunately, the stubble land that holds most of the snow is usually drier and warmer than summerfallow and is in a better condition to absorb moisture.

During the summer months, the temperatures in the two plots differed by only a few degrees. The effects of snow coverage were usually erased by the middle of May after which the fallow heated up more rapidly than the seeded plot. By July the fallow temperatures were a degree or two higher at all depths than those under the crop.

SOIL FERTILITY

The prairie soils are relatively new from an agricultural viewpoint for the majority of the land was broken during the early part of the 20th century. The parent material of these soils was glacial drift, composed of a wide variety of minerals. Owing to the low rainfall and high evaporation, there has been little loss of plant nutrients by leaching. These same climatic conditions have aided in the formation of a calcium carbonate layer within 18 inches of the surface. In the heavier soils calcium carbonate may be found within a few inches of the surface. If an adequate supply of organic matter is maintained. there is little indication that an appreciable drop in crop yield, due to a lack of plant nutrients, will take place in the immediate future.

The nitrogen content of the brown soils varies from 0·14 to 0·30 per cent in the 0-6 inch layer and decreases very rapidly with depth. The dark brown soils contain a higher percentage of nitrogen. The total phosphorus varies from 0·04 to 0·07 per cent and shows little change to a depth of 3 feet. The prairie soils are approximately neutral in reaction with the majority falling between pH 6 and pH 7 (26). A sample more acid than pH 5·5 is rather rare. Soils more alkaline than pH 7·2 contain appreciable quantities of calcium carbonate or water soluble salts. The potassium content of the prairie soils is high.

Commercial Fertilizers

The statement was previously made that water was the first limiting factor in crop production in the brown soil zone. Greenhouse, plot and field experiments with commercial fertilizers have not indicated a definite lack of any of the elements essential for plant growth. During years of favourable moisture conditions, increased yields may be obtained by the use of phosphate fertilizers and especially ammonium phosphate. The clay soils are more likely to respond to fertilizers than the lighter soils. The dark brown soils give a more consistent response to phosphatic fertilizers and their use is increasing on these soils. Experimental work in regard to the use of commercial fertilizers is being continued.

Nitrate Production and Use by Crops

It is a more or less accepted fact that nitrogen is one of the last elements to become a limiting factor under dry land agriculture.

A comparison of virgin and cultivated soils shows a loss of approximately 20 per cent of the nitrogen due to cultivation (36). However, under favourable moisture conditions, the crops on the brown soils are always dark green in colour indicating an adequate supply of nitrogen.

Soil samples were collected at seeding time from a total of 138 summer-fallow fields during a 4-year period. These fields were within a radius of 75 miles of Swift Current and the soils varied in texture from sandy loam to heavy clay. The average nitrate nitrogen in the 0-6 inch layer was 18·2 p.p.m. or 36·4 pounds per acre which is enough nitrogen to produce 18 bushels of wheat.

The nitrifying power of the brown soils was determined by incubation under laboratory conditions. Samples of soil were collected in the fall from 30 fields that had produced crops that year. The fields sampled had all suffered more or less from wind erosion. The nitrate nitrogen content of the samples, which varied from 1 to 14 p.p.m., was increased to 75 p.p.m. or more in 4 weeks time. The addition of finely ground alfalfa to a second series of the same samples gave a much greater increase in nitrate during the 4-week period showing that a very active nitrifying flora was present in these soils.

Detailed information in regard to the concentration of nitrate nitrogen in cropped and fallowed land was obtained by the systematic sampling of a 3-year rotation of fallow-wheat-wheat for a 6-year period, giving two complete cycles of the rotation. The field was divided into 3 strips, each representing one year of the rotation, thus information was obtained for the complete rotation each year and for two complete cycles of the rotation.

Soil samples for nitrate and moisture determinations were collected at definite locations from April to October each year. The average concentration of nitrate nitrogen for the 6-year periods at depths of 0-6, 6-12 and 12-24 inches are shown in Table 16.

The first samples were collected in the spring as soon as the frost was out of the ground, which was during the first 2 weeks of April. Samples were collected again at seeding time, which was near the first week in May and then

at 2-week intervals until the crops were ripe. Samples were also collected late in the fall. The sampling dates have been grouped for definite periods and the average nitrate nitrogen computed for the different depths.

TABLE 16.—NITRATE PRODUCTION UNDER FIELD CONDITIONS

Average of 6 years (1939–1944 inclusive)

Period	Depth	Crop on fallow N as NO_3	Crop on stubble N as NO_3	Fallow area N as NO_3
	inches	p.p.m.	p.p.m.	p.p.m.
April	0– 6	29·0	6·6	7·5
	6–12	16·1	10·8	9·3
	12–24	8·3	5·0	6·9
May 1–15	0– 6	29·8	7·1	6·0
	6–12	17·5	11·3	8·6
	12–24	7·6	7·8	7·3
May 16–31	0– 6	17·6	10·3	6·6
	6–12	19·0	12·6	10·6
	12–24	13·3	7·6	13·0
June 1–15	0– 6	17·1	6·0	4·1
	6–12	15·0	6·0	4·6
	12–24	9·0	5·9	3·9
June 16–30	0– 6	10·3	4·3	7·3
	6–12	10·0	3·6	3·9
	12–24	7·3	2·5	3·1
July 1–15	0– 6	5·2	2·5	11·0
	6–12	5·1	3·6	4·3
	12–24	2·3	2·3	3·0
July 16–31	0– 6	5·8	3·0	15·0
	6–12	4·8	2·3	5·3
	12–24	2·5	1·9	3·3
August	0– 6	3·2	1·5	19·2
	6–12	3·0	1·1	6·2
	12–24	2·4	1·0	3·2
September	0– 6	3·1	2·6	29·3
	6–12	1·3	1·0	8·0
	12–24	1·0	1·0	6·0
October	0– 6	4·3	6·9	21·0
	6–12	4·6	7·0	8·5
	12–24	3·6	2·1	4·1

The crop growing on land fallowed the previous year had access to a higher concentration of nitrate than the stubble crop, owing to the build-up during the fallow year. In both cases, the nitrate content of the surface soil was reduced to a few parts per million by the first of July and remained low until harvest showing that the crop was using the nitrate as fast as it was formed. The dark green colour of the crops indicated that adequate supplies of nitrate were available. There was some evidence of an increase in nitrate after harvest when moisture conditions were favourable and there was little or no weed growth.

During years of low moisture supply, when the crop was suffering from drought, there was a higher concentration of nitrate in the soil than when rainfall was more plentiful, there being more nitrate than the plants were able to use. When the moisture supply was adequate the nitrate content was often reduced to 1 p.p.m. or less by the end of June.

The land being fallowed showed little change in nitrate during April or May. The first cultural treatment was given during the first week of June

at which time the land was often covered with a thick stand of weeds, which had used the nitrate that was formed. Soil temperatures are low during April and May and do not attain a temperature favourable to rapid nitrification until the end of May or the first part of June. The decomposition of the plant residue on the fallow land would use up part of the nitrate during the early part of the fallow period. For these reasons, the build-up of nitrates in fallow land is rather slow until the middle of July, reaching a maximum the latter part of August or early September.

There is little evidence of leaching of nitrates beyond the depth of 24 inches and it is doubtful if any is carried beyond the depth of root penetration. The roots of spring wheat will reach a depth of 42 to 45 inches under the soil and climatic conditions found in Western Canada.

Effect of Straw on Nitrate Formation

The recommended cultural practice for the prairie areas is to return all crop residue to the land. This practice is followed almost universally for practically all grain is cut with a combine harvester. This means that from 1,000 to 2,000 pounds of straw per acre will be left on the field and gradually worked into the surface soil by subsequent cultural operations. As the nitrogen content of straw is generally below the critical limit of 1·4 per cent, more or less of the soil nitrates will be utilized by the bacteria which bring about the decomposition of the straw. This reduction of available nitrate is not important in a field being summerfallowed but might be if the land was seeded immediately to a stubble crop.

The effect of straw on nitrate production, under laboratory conditions, was determined by incubating samples of soil and soil plus finely ground straw at the rate of 2 tons per acre. Triplicate samples were analysed each week for an 8-week period. The results of the experiment are shown in Table 17. The addition of the straw caused a reduction in the original nitrate content of the soil. By the end of 3 weeks the concentration was back to the original and showed a gradual increase with time but did not attain as high a concentration as the soil alone during the 8-week period.

TABLE 17.—EFFECT OF STRAW ON NITRATE ACCUMULATION

—	N as NO_3 after incubation (Weeks)								
	Start	1	2	3	4	5	6	7	8
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Soil	8	18	26	32	39	44	50	54	62
Soil and straw	8	3	5	9	16	21	28	36	42

These results tend to confirm field observations that the working in of a heavy crop of straw during the fallow period will not cause the following crop to suffer from a lack of nitrate. When a crop is seeded immediately after working in a heavy crop of straw the crop may suffer from a lack of nitrate for 8 to 12 days. This condition has been observed on a few occasions but was corrected in a relatively short time. It is more likely to occur on heavy wet soil where temperature and other conditions are not favourable for nitrate production.

From the information available, it is evident that, if the organic matter of the prairie soils is maintained at or near its present level, the soil will continue to supply sufficient nitrogen for good crop production.

Accumulation of Nitrate in Oat Straw

Attention has been directed on several occasions to the poisoning of livestock by the ingestion of oat hay or straw containing a high percentage of nitrate (4, 24). Experimental work has shown that a soil with a high concentration of nitrate due to natural agencies or fertilizers tends to produce a crop with a high nitrate content. Drought during the later stages of growth may also increase the nitrate content (27). Crops grown on summerfallow may have a higher nitrate content than crops grown on stubble land since the nitrate content of the fallow soil may be higher at seeding time. Crops subject to extreme drought throughout the growing season are generally low in nitrate content.

The data in Table 18 show the total and nitrate nitrogen in samples of oat straw and grain from adjacent fields. The total nitrogen content of the straw samples reported is higher than the average generally found in ripe straw.

There was a wide variation in the total nitrogen of the different samples for both grain and straw. The nitrate content of the straw shows a much wider variation, being quite high in some samples. No grain sample has been analysed that had a high concentration of nitrate nitrogen. There was no apparent relationship between high nitrogen and high nitrate in the straw. The high nitrogen content of some straw samples would give them a high feeding value provided the nitrate content was not sufficient to be dangerous.

TABLE 18.—TOTAL AND NITRATE NITROGEN IN OAT STRAW AND GRAIN

Crop on	Straw		Grain	
	Total N	N as NO_3	Total N	N as NO_3
	per cent	per cent	per cent	per cent
Summerfallow	1·45	0·259	2·84	0·012
Stubble	0·84	0·026	2·18	0·004
Summerfallow	1·13	0·556	2·41	0·013
Stubble	0·36	0·004	1·79	0·002
Summerfallow	1·17	0·406	2·52	0·023
Stubble	0·80	0·060	2·23	0·005

Approximately 31 per cent of the field samples of oat straw examined in 1941 contained 0·2 per cent or more of nitrogen as nitrate. As this is the tentative lower toxic limit (4), many of these crops would be considered potentially dangerous. The majority of these crops were grown on summerfallow land and subject to drought during the later stages of growth. Only 4 samples out of 35 examined from the 1942 crop, which was well supplied with moisture, contained 0·2 per cent or more of nitrate.

Analytical results indicate that the nitrate is present as potassium nitrate.

Organic Matter

The cultural methods followed for many years in the prairie areas were contributory to the rapid loss of organic matter and soil erosion. During the past 15 years there has been considerable change in cultural practice due to the almost universal use of the surface tillage implements and the combine harvester. This has not reduced the percentage of land in fallow but the use of the stubble mulch or trash cover has given more or less control of erosion. The ultimate effect of the returning of all crop residue on the organic-matter content of the soil is of particular importance.

Grasses or legumes do not fit into the present short-term rotations followed in the prairie areas. Thus the inclusion of such crops for increasing the organic matter in the soil would necessitate a definite change in cultural practice.

A comparison of adjacent virgin and cultivated soils by Newton, Wyatt and Brown (36) showed that the cultivated brown soils had lost approximately 20 per cent of the organic matter. The rate of loss was more rapid during the early years of cultivation. The average yearly loss, as determined for all fields, was approximately 848 pounds per acre.

Soil samples have been collected by this Laboratory from three fields at the time of breaking and at periodic intervals thereafter. During the first 7 years after breaking, the average loss of organic matter was 22 per cent.

Soil samples taken from fields of crested wheat grass and brome grass at the time of breaking and 2 years later showed that the loss of organic matter in the 2 years after ploughing was equal to the gain during the previous 4 years in grass. Determinations of organic matter have been made at 2-year intervals on fields that were seeded to grass. These fields have now been in grass for 8 years and where good stands were obtained on sandy loam, there was an increase of 2 to 3 tons per acre in organic matter, on loam soils the increase was from 3 to 5 tons per acre. On some light soils, where poor stands were obtained, there was a loss of 2 to 3 tons per acre of organic matter. The available data indicate that the accumulation of organic matter in fields seeded to grass is rather slow in the brown soils and the loss of organic matter, after such fields are broken, is quite rapid.

Comparative information on the rate of loss of organic matter from samples of sod and cultivated soil was obtained by the following laboratory experiment. Samples of soil were collected from adjacent fields of grass and cultivated land. The samples were air dried, pulverized in a mill to pass a 1 mm. sieve and then incubated under favourable conditions of moisture and temperature (28). The decomposition of organic matter was calculated from the carbon dioxide evolved by the samples. The data in Table 19 show the chemical composition of the soils and the organic matter lost during an incubation period of 31 days.

TABLE 19.—AVERAGE COMPOSITION OF SOILS AND LOSS OF ORGANIC MATTER AS CARBON DIOXIDE

—	Cultivated land	Native sod	C.W. sod	Brome sod
Number of samples	13	10	5	2
Total nitrogen (per cent)	0·216	0·272	0·254	0·261
Total organic matter (per cent)	3·43	4·89	4·50	4·48
O.M./N ratio	15·87	17·65	17·71	17·16
O.M. lost in 31 days (per cent)	1·54	2·49	3·14	2·71
O.M. lost in 31 days (lb./acre)	1,035	2,325	2,842	2,306

The results show that the sod samples lost organic matter more than twice as fast as the cultivated soils. The incubation period was extended to 69 days for 10 of the samples. A comparison of the average loss for the first and last 15 days of the 69-day period showed that the cultivated soils were losing organic matter at two-fifths of the original rate and the sod samples at one-third the original rate. The maximum evolution of CO_2 occurred during the first 10 days and was followed by a gradual reduction in rate. The samples from cultivated soils reached a fairly uniform rate in about 21 days and the sod samples in 35 days.

The return of all crop residue from a 10-bushel crop would add approximately 900 pounds of organic matter per acre. Although most of this material would decompose fairly rapidly, it would aid materially in maintaining the organic-matter content at a favourable level.

The relative rate of decomposition of different types of plant material was determined by incubating mixtures of finely ground plant material and soil and measuring the carbon dioxide evolved. In one experiment the crown and roots of native and cultivated plants were used and in another case just the tops. The results of these experiments are reported in Table 20.

TABLE 20.—RATE OF DECOMPOSITION OF PLANT MATERIAL

Plant material	N.	C.	C/N.	C. evolved in 65 days	
	per cent	per cent	ratio	mgm.	per cent
CROWN AND ROOTS					
Carex filifolia	0·73	42·7	58·5	59·1	13·8
Agropyron cristatum	1·47	31·8	21·6	118·8	37·3
Bouteloua gracilis	0·71	34·1	48·0	119·2	34·9
Agropyron pauciflorum	1·15	35·1	30·5	130·4	37·1
Stipa comata	0·82	35·7	43·5	134·2	37·6
Bromus inermis	1·38	42·0	30·4	158·5	37·7
Agropyron Smithii	0·74	43·7	59·0	204·0	46·7
Melilotus alba	1·08	45·5	42·2	213·0	46·7
Medicago sativa	1·31	44·5	34·0	236·4	52·8
TOPS					
Triticum vulgare	0·60	45·7	76·2	169·4	37·1
Avena sativa	0·81	44·2	54·5	177·0	40·1
Linum usitatissimum	1·22	46·0	37·7	145·0	31·5
Melilotus alba	2·21	46·0	20·8	193·0	41·9
Medicago sativa	2·89	44·6	15·4	198·2	44·4
Salsola pestifer	2·81	39·6	14·2	176·5	44·6

The crown and roots were composed of new and old material, no attempt being made to secure roots of the same age, except that the plants were all collected within a 2-day period near the end of July. However, the relative rate of decomposition has been fairly consistent for material of the same species collected at various times, when measured as in this experiment.

The data show no consistent relationship between nitrogen content or C/N ratio and carbon evolved, indicating that the nature of the complex organic compounds was the determining factor.

The crown and roots of thread leaved sedge *Carex filifolia* Nutt., decomposed more slowly, and alfalfa *Medicago sativa*, more rapidly than any of the root materials studied. Western wheat grass *Agropyron Smithii* Rydb., decomposed almost as rapidly as alfalfa or sweet clover *Melilotus alba.*, though having a much lower nitrogen content and wider C/N ratio. Similar results might not be obtained under field conditions owing to the difference in the size of roots.

The tops of the plants used for experimental purposes represented the growth of one season and contained no material that had undergone any decomposition. There was a fairly consistent relationship between nitrogen content, C/N ratio and carbon evolved, the plants with a low nitrogen content and wide C/N ratio tending to decompose more slowly. The rapid decomposition of alfalfa, sweet clover, and Russian thistle *Salsola pestifer* A. Nels, is in keeping with field observations.

Practically all the plant materials studied decomposed most rapidly during the first 5 to 7 days of the incubation period, gradually slowing down and approaching a fairly uniform rate by the end of 65 days. The carbon evolved

during the first 15-day period was approximately 70 per cent of that evolved in 65 days. There is a very rapid loss of the easily decomposed fraction, with the decomposition of the more resistent portion proceeding at a much slower rate.

Effect of Alkali Salts on Crop Growth

The effect of alkali salts on crop growth is of particular importance in the irrigated lands of southwestern Saskatchewan. A high proportion of these areas is low lying and contains appreciable quantities of water-soluble salts. The major portion of the water-soluble salts comprises sulphates of calcium, magnesium and sodium. The bicarbonates and chlorides are generally low and very few samples contain even a trace of sodium carbonate. Calcium is generally the predominant cation in the soils of low salt concentration and sodium in the soils of medium or high concentration.

Greenhouse experiments using pot cultures have indicated that concentrations of water-soluble salts below 0·4 per cent caused only a slight reduction in the yield of 5 successive crops of alfalfa (25). Where the concentration was 1·09 per cent the yield of alfalfa was 35 to 67 per cent of the yield in soil containing 0·157 per cent soluble salts. The milli-equivalents of sodium were greater than those of calcium or magnesium in these soils.

Samples of soil collected in fields from areas of good and poor crop growth showed a wide variation in salt content. Concentrations that are toxic at one location may have little apparent effect at others, indicating that other factors are modifying the results.

Data are presented in Table 21 showing the variation in crop growth and salt concentrations within short distances. Each pair of samples at a given location was collected within a distance of 10 feet, and represent more or less extreme conditions. These samples were from irrigated areas where adequate water was supplied for crop growth. Samples collected from non-irrigated areas have generally shown a toxic effect from lower concentrations than those listed for irrigated land, indicating that the soluble salts are more toxic when moisture conditions are not favourable.

TABLE 21.—EFFECT OF WATER-SOLUBLE SALTS ON PLANT GROWTH

Location	Crop	Condition of crop	Depth	pH	Total salts	Total $-CaSO_4$
			inches		per cent	per cent
1	Oats	Poor 12″	0–12	8·3	2·47	1·89
			12–24	8·7	1·64	1·53
		Good 48″	0–12	7·7	0·31	0·10
			12–24	7·8	0·88	0·54
2	Oats	Poor 14″	0–12	8·1	0·55	0·49
			12–24	8·2	1·11	0·97
		Good 48′	0–12	8·1	0·10	0·08
			12–24	8·1	0·48	0·35
3	Wheat	Poor 12″	0–12	8·3	0·64	0·58
			12–24	8·4	2·09	1·44
		Good 38″	0–12	7·8	0·71	0·32
			12–24	8·2	0·53	0·38
4	Wheat	Poor 12″	0–12	8·4	0·91	0·81
			12–24	7·7	1·89	1·55
		Good 38″	0–12	8·0	0·18	0·14
			12–24	8·1	0·25	0·19
5	Flax	Poor	0–12	8·0	0·71	0·54
			12–24	8·6	1·42	1·15
		Good	0–12	7·8	0·08	0·05
			12–24	8·1	0·07	0·04

Calcium sulphate is not a toxic salt and is considered as having a beneficial effect in reducing the toxicity of other salts. A series of experiments was set up in the greenhouse to determine the effect on plant growth of varying the amount of calcium sulphate in a mixture of other sulphates.

The soil used for experimental purposes was relatively free of water-soluble salts. Glazed gallon crocks were used as containers. A sulphate mixture was made up containing 1, 1 and 3 milli-equivalents of Ca, Mg and Na respectively. This mixture was added in increasing amounts to the first series of crocks to give theoretical concentrations of 0·5, 0·7, 0·9, 1·1 and 1·3 per cent of water-soluble salts.

A second series was set up using a mixture of magnesium and sodium sulphates in the proportion of 1 and 3 milli-equivalents of Mg and Na. This mixture was added to give theoretical concentrations of 0·4, 0·56, 0·72, 0·88 and 1·04 per cent. A constant amount of calcium sulphate was added to each crock to give a concentration of 0·07 per cent or 1 M.E. Ca per 100 gm. soil.

To a third series of crocks only magnesium and sodium sulphates were added, these being in the same proportion and amounts as the previous series. All treatments were in triplicate.

The crocks were all seeded to alfalfa and 5 crops were harvested. The crocks were then all cultivated, reseeded to alfalfa and 2 more crops harvested.

The various treatments and total yields from the 7 crops are set out in Table 22. The different series all show the same trend in reduction of yield with increased salt concentration. There was no apparent difference due to the variation in amount of calcium sulphate.

TABLE 22.—EFFECT OF ALKALI SALTS ON YIELD OF ALFALFA

Theoretical salt concentration	Total yield	Average yield per crop
Per cent	gm.	gm.
Check	45·59	6·51
0·5	37·73	5·39
0·7	34·23	4·89
0·9	27·12	3·88
1·1	22·62	3·23
1·3	22·50	3·21
Constant amount $CaSO_4$—		
0·07	51·56	7·36
0·47	42·76	6·11
0·63	37·66	5·38
0·79	30·09	4·29
0·95	27·76	3·96
1·11	17·52	2·50
No $CaSO_4$ added—		
Check	45·59	6·51
0·40	40·13	5·73
0·56	33·56	4·79
0·72	31·86	4·55
0·88	26·09	3·72
1·04	22·46	3·21

Other analyses in regard to water-soluble salts have not indicated a greater tolerance of salts when appreciable quantities of calcium sulphate were present. It may be that a small amount of calcium is just as effective as a larger amount and in this experiment the soluble calcium in the soil may have been sufficient. It is suggested that the benefit may be more from the effect of the calcium on the physical condition of the soil rather than an antagonistic effect. The soil used in this experiment was in good physical condition and the reduction in yield at the concentration of 1·1 and 1·3 per cent was not as great as generally found under field conditions.

Occurrence of Selenium

Cattle suffering from selenium poisoning have been observed in southwestern Saskatchewan. Such cases are more likely to appear during dry years when forage is scarce and over grazing takes place.

The selenium indicator plants, *Astragalus pectinatus* and *Astragalus bisulcatus* are quite prevalent over a wide area. They are not palatable and are seldom eaten by livestock unless there is a scanty supply of other forage. The grasses seldom accumulate a large amount of selenium even on seleniferous soils. Very few of the plants analysed, other than indicator plants, have contained toxic amounts of selenium and no definite relationship has been found between the selenium content of soils and plants nor have analyses of soil profiles shown a definite horizon of selenium concentration.

SOIL EROSION BY WIND

Soil erosion by wind is a serious problem in the prairie areas and cultural methods that will give the maximum control of this recurring hazard, must be followed at all times. The basic factors concerned with this problem have constituted one of the major lines of research.

Water erosion is becoming more prevalent and this phase of soil erosion is being incorporated in the Laboratory program.

The work pertaining to wind erosion of soil has been divided into three main phases: the dynamics of wind erosion with special reference to methods of control; the physical and chemical soil properties influencing wind erosion; the relative effects of different cultural methods on erosion control.

Since many aspects of the soil drifting problem could not be studied solely with field experiments, two wind tunnels were constructed, one in the laboratory and one for field use. At the time the construction of the tunnels was undertaken in 1936, no information was available on their feasibility for the study of soil erosion. Bagnold's results (1) on the movement of sand by wind in a wind tunnel were published soon after and served as a useful background for this work. The construction of the laboratory tunnel was begun in accordance with suggestions received from the Aeronautical Branch of the National Research Council of Canada, modified and revised after many preliminary trials, and finally completed in 1938. The plan of the tunnel now in use is indicated in Fig. 12.

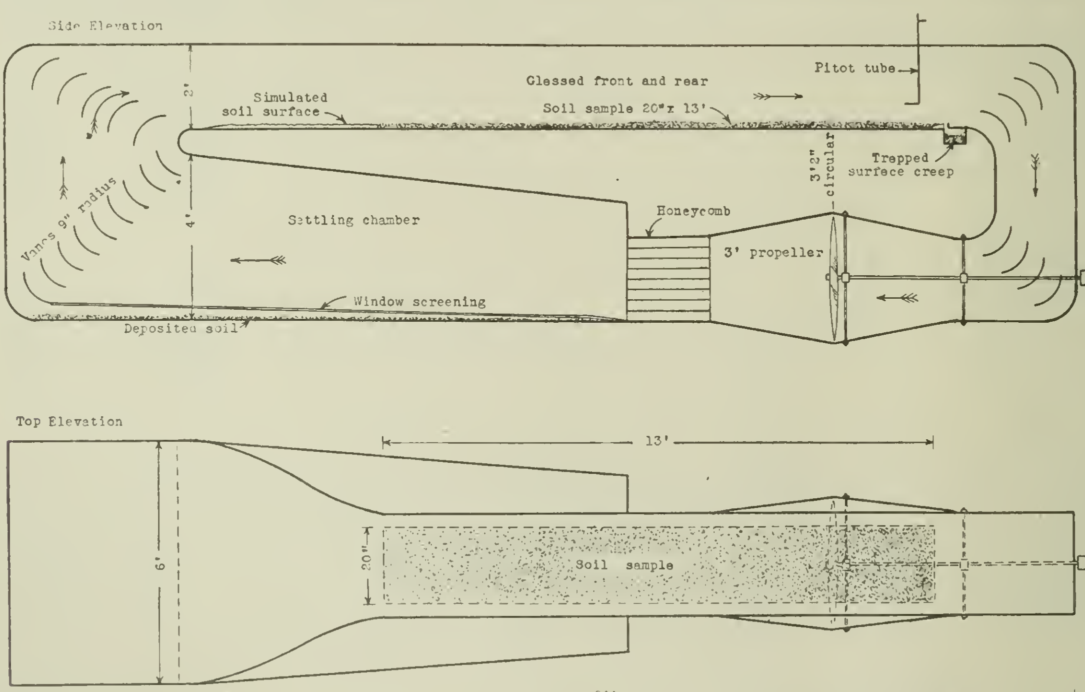


Fig. 12.—Plan of the Laboratory wind tunnel.

The details of construction of the portable tunnel were published previously (6, 9). Fig. 13 shows this tunnel as it is used at present to test the erosiveness of a soil under field conditions.

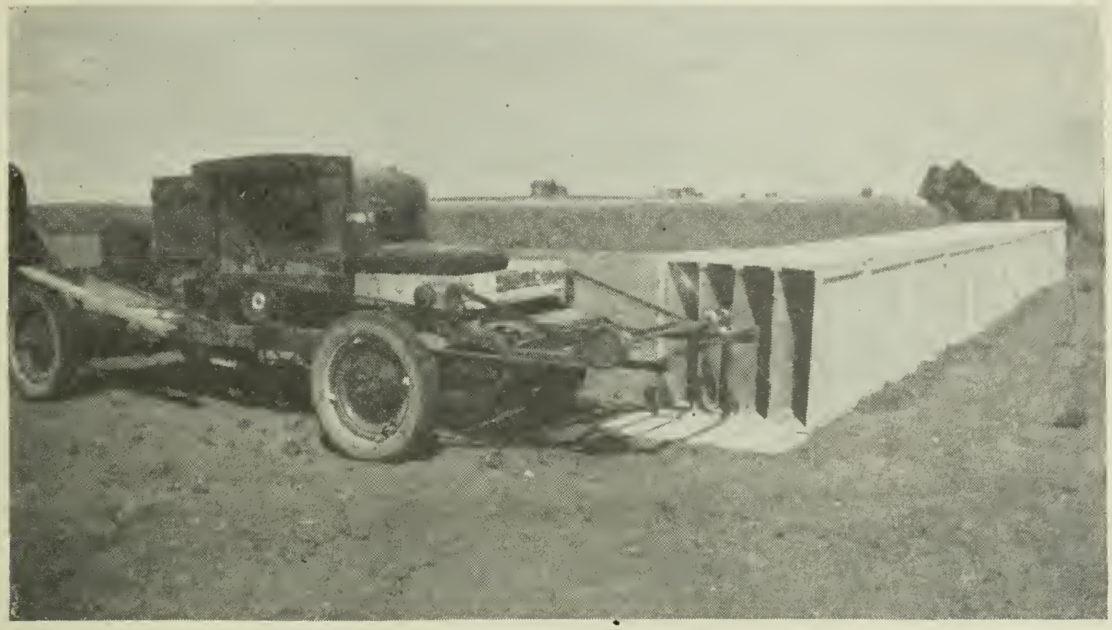


Fig. 13.—Portable wind tunnel as used in the field.

Dynamics of Wind Erosion

The energy relationships between wind and soil are of greatest importance in the problem of wind erosion control. The erosion of the soil by wind is a complex process involving many factors, the more important of which are:

Air	*Ground surface*	*Soil*
Velocity	Roughness	Structure, affected by
Turbulence	Cover	Organic matter
Density, affected by	Obstructions	Carbonates
Temperature	Temperature	Texture
Pressure	Topographic features	Specific gravity
Humidity		Moisture content
Viscosity		

The factors involved in any condition are at least several in number and are usually subject to considerable variation. Needless to say, these must be understood if reliable practices of soil erosion control are to be established.

The Character of the Wind Near the Ground

The wind near the earth's surface differs in velocity and turbulence from that in the upper atmosphere because of surface friction. At some level among the irregularities of the ground surface, the average velocity of the wind is zero. From this level upwards it increases rapidly at first, and less and less rapidly with height to about 1,000 to 1,500 feet.

The velocity distribution of the wind near the ground is governed by a definite aero-dynamic law and is dependent on the nature and the degree of roughness of the ground surface. When the velocity is expressed in terms of the logarithm of height the curve of velocity becomes a straight line, as indicated in Fig. 14. The velocity distribution curves obtained either in the wind tunnels or the open field were found to fit well into Prandtl's formula which gives the mean velocity of any fluid in terms of the magnitude of friction per unit area

of surface, the height of measurement above ground, and the degree of surface roughness. In Fig. 14 the straight lines *a*, *b*, and *c* meet the ordinate at numerical values of 0·06, 0·04 and 0·008 inches which, according to Prandtl's formula, should correspond to surface roughness of 30 times this magnitude or 1·8, 1·2 and 0·24 inches. These values were found to agree approximately with the actual irregularities of the ground surface, irrespective of whether the measurements were made in a tunnel with an artificial wind or under natural conditions in the field. Numerous measurements showed that the velocity of the wind near the ground was dependent mainly on the nature of the surface and the irregularities of the height of surface obstructions.

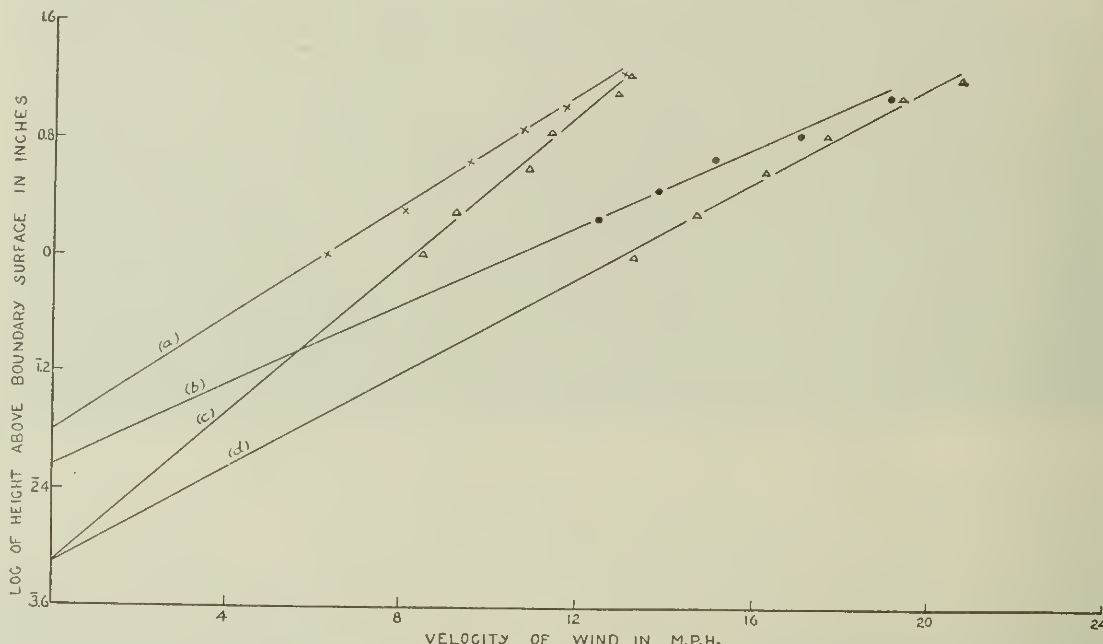


Fig. 14.—Wind velocity at different heights over various types of ground surface. *(a)* Very cloddy, bare fallow; *(b)* standing wheat stubble 7 inches high; *(c)* smooth, bare fallow; *(d)* same as *(c)* with wind velocity increased.

Measurements with specially designed oscillating plates (10) have shown that the wind near the ground is characterized by many eddies of extremely variable velocities, the predominant movement of the eddies being a clockwise rolling action. The degree of eddying, or turbulence, varies directly with the roughness of the ground and inversely with the height. When the roughness of the ground surface remains the same the increased turbulence has a marked tendency toward increasing the surface velocity and hence the frictional force between the wind and the ground. That turbulence had a marked bearing on soil erosion, was indicated by Parkinson (37), who observed that the presence of dust storms depended on the instability, or turbulence, of the air masses involved. In the final analysis the large-scale turbulence referred to by Parkinson is of little practical concern, for it is impossible to effect any marked control of the air masses involved. The character of the wind near the ground, however, can be modified by human action.

The frictional eddies are usually formed when the variation of wind velocity with height exceeds a critical limit. This critical limit is encountered at velocities below or equal to those required to initiate soil drifting, but never above. Soil drifting under non-turbulent flow of air has not been recorded.

Since turbulence increases the erosion of the soil, other factors being equal, it may be assumed that cultural practices tending to decrease turbulence of wind would tend to reduce erosion. However, some of the methods of control now in use are based on the principle of placing obstructions in the path of the wind to break its force. The presence of clods, stubble, or ridges increases

turbulence, but the importance of such obstructions lies in the fact that they absorb much of the force of the wind, thus reducing the velocity and allowing only the residual velocity to act on the soil. It was found that ridging the ground surface increased turbulence, but in spite of that, the rate of soil flow decreased markedly. Whatever effect the increased turbulence resulting from wind striking ground obstructions has in increasing erosion is more than offset by the reduced average velocity of the surface wind.

Natural variations in air density, as affected by variations in temperature, pressure, or humidity, were shown (17) to have but little effect on soil drifting. Natural changes in viscosity likewise have but little effect on the erosive force of the wind. Tests have shown, on the other hand, that even a slight reduction in velocity of the wind near the ground produces a significant reduction in the amount of soil transported because the force of the wind varies as the square of its velocity. The transport capacity of the wind is therefore affected markedly by two factors—gustiness and velocity. There is little that can be done to reduce gustiness, but surface velocity can be modified considerably by various measures. Reduction of velocity near the ground should be one of the main principles of soil drifting control.

The Nature of Soil Erosion

The erosive soil fractions are carried by wind in three types of movement (15): *surface creep*—rolling and sliding along the surface; *saltation*—jumping and bouncing; and *suspension*—floating in the air stream.

The greatest proportion of the movement on arable soils is by particles in saltation. These particles constitute the most erosive particles and generally range from 0·05 to 0·5 mm. in diameter. While being rolled by the wind, the particles suddenly rise almost vertically to form the initial stage of the movement in saltation. After rising steeply into the air (Fig. 15), the particles gain considerable forward momentum from the pressure of the wind. On striking the surface, they may rebound and continue their movement in saltation, or lose most of their energy by striking other erosive particles, causing them to either roll or slide or to rise upwards and become part of the saltation movement. It is evident that the movement of soil by wind is dependent not so much on the force of the wind acting on the surface of the ground, as on the velocity distribution of the wind to the height of saltation. This height is limited, hence it may be concluded that soil drifting is essentially a surface phenomenon and is therefore not directly dependent on the condition of the wind above that restricted height.

The particles in surface creep are moved by the impacts of the particles in saltation and not appreciably by the direct impact of the wind. These constitute the largest of the erosive particles, ranging from about 0·5 to 1 mm. in diameter.

The lifting of fine dust into the atmosphere is likewise the result of movement of particles in saltation. Contrary to general opinion, dust less than 0·05 mm. and particularly less than 0·01 mm. in diameter is extremely resistant to erosion by wind but when mixed with coarser particles capable of movement in saltation, is readily lifted into the air. The resistance of dust to wind erosion is due primarily to the existence of a slow-moving, viscous layer of air, seldom less than 0·05 mm. in depth, over the surface of the ground. The tiny particles have to be lifted above this viscous layer into the faster moving, turbulent stream above, before they can be transported by the wind. The only way they can be lifted off the ground is to be kicked up by the particles moving in saltation. The particles in saltation, on the other hand, are moved readily by direct wind pressure, since they project through the viscous layer and into the faster-moving turbulent air above.

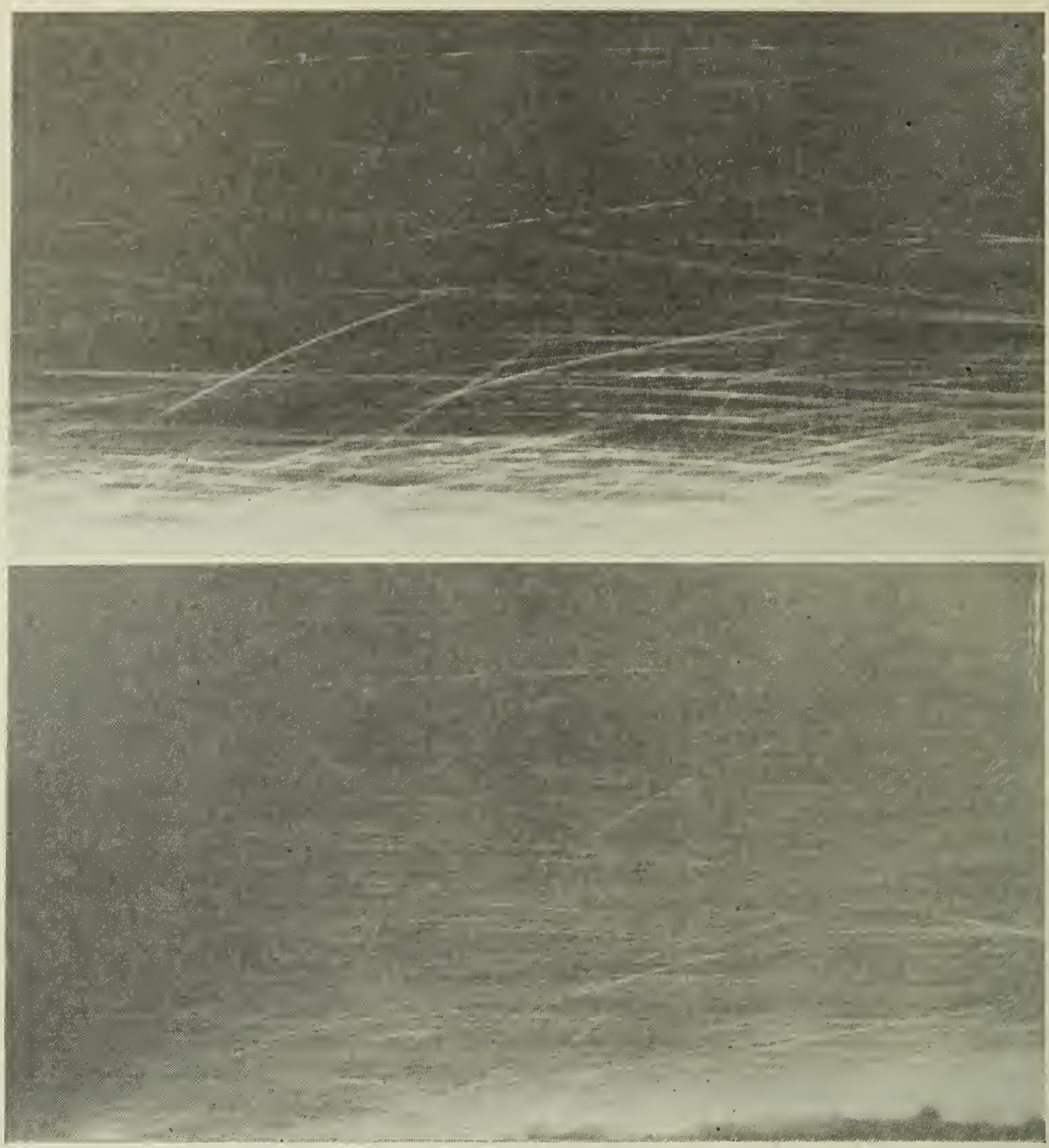


Fig. 15.—Photographs of wind blown soil particles, showing (upper) movement of dune sand in saltation and (lower) fine sandy loam in saltation and suspension.

The transport of dust through the air is facilitated by the turbulent nature of the air stream. Measurements have shown that the average upward velocity of the eddies for an erosive wind is at least 2 or 3 miles per hour—sufficient to lift and support indefinitely quartz particles of the size of silt. Dust can therefore be transported great distances from the eroding area and will come down to earth only with rain or when the velocity of the wind has slackened.

The proportion of the three types of movement varies greatly for different soils. In the cases examined, between 50 and 75 per cent of the weight of the soil was carried in saltation, 3 to 40 per cent in suspension, and 5 to 25 per cent in surface creep.

The concentration of soil particles carried by wind is greatest at the surface of the ground and decreases rapidly with height. The coarse particles tend to move closer to the ground than the fine ones. Typical examples are shown in Fig. 16 of the relative quantity and diameter of soil particles carried at different heights above the surface of loam and clay loam. These curves show that from 60 to 80 per cent of the total quantity of soil is transported at a height

of 0 to 2 inches, over 90 per cent below a 12-inch height, and only a small trace is carried above 38-inches. Clay and sandy soils were observed to drift closer to the ground than the medium-textured soils, due to larger quantities of coarse particles that could be carried by the wind.

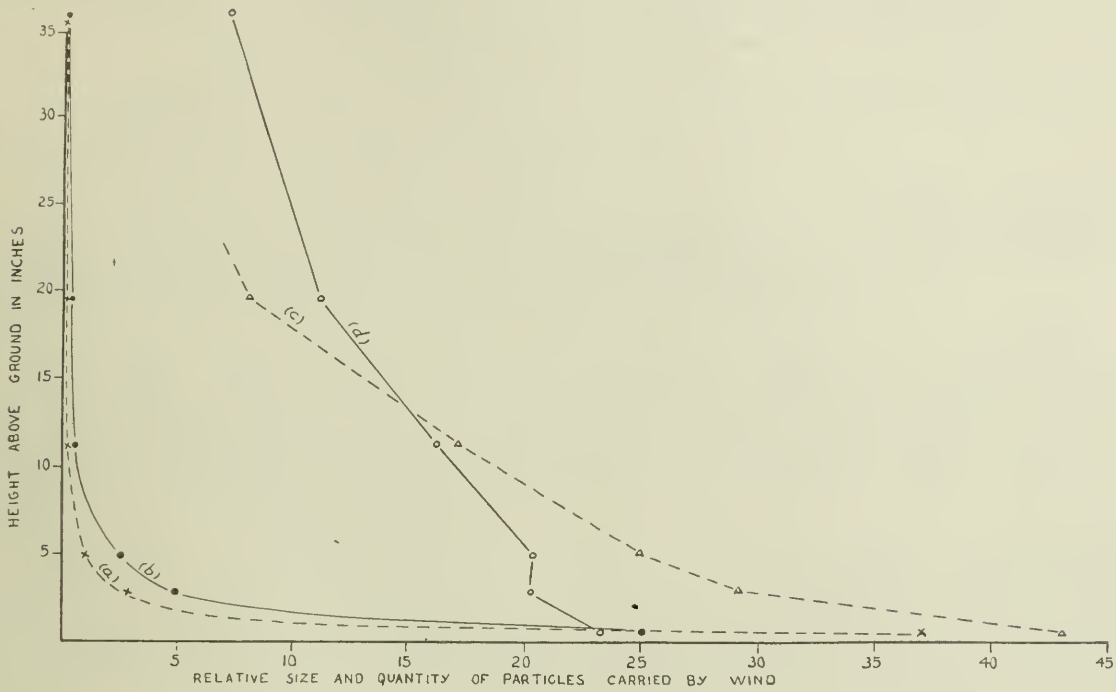


Fig. 16.—Approximate curves showing *(a)* the relative quantity of soil carried at various heights over eroding Sceptre heavy clay; *(b)* over Cypress loam; *(c)* the relative average diameter of blown soil grains in 1/100 mm. over Sceptre clay; *(d)* over Cypress loam.

The height to which particles in saltation rise has an important bearing on the most effective methods of soil drifting control. The capacity of stubble or ridged strips to trap the moving soil, and hence to reduce drifting, was found (15) to be governed to a large degree by the height of jump of particles in saltation.

The most readily eroded soil particles range from 0·05 to 0·15 mm. in diameter (Fig. 17) and require a velocity of 8 to 9 m.p.h. at a 6-inch height to initate and continue their movements. Above this range of size the minimum velocity of wind required to initiate the movement, *threshold velocity,* increases with the increase in the size of particles, while below this it increases with the decrease in the size of particles. For mixtures of different sizes of particles, the threshold velocity was found to be lower than that required to erode only the largest particles. The threshold velocity was found to vary directly with the average size and inversely with the range of size of the component particles. The movement of the coarse fractions is produced mainly by the bombardment received from the smaller particles moving in saltation.

The velocity required to initiate soil drifting in cultivated fields depends on a complicated set of factors. The initiation of soil drifting for the first time in any given season requires a much higher velocity than for succeeding windstorms. One reason why a high initial velocity is required to start the movement of soil is the existence of a surface crust, often caused by rain or melting snow. Under continual exposure to erosion, the surface crust may become abraded and expose the more erosive soil beneath. Another reason is the sorting action of the wind, causing the accumulation of dune materials requiring a much lower threshold velocity than the unsorted material of a non-eroded field. The threshold velocity for dune material is the lowest possible in the field and varies

but little with soil type. There is a wide range of threshold velocities for any soil (16), depending on the previous history of the field. This range varies from 13 to 15 miles per hour at 1-foot height above a smooth ground surface or for fields that have been seriously affected by soil drifting. To prevent an erosive soil from drifting, it is necessary to reduce the velocity of the wind near the ground below this critical value. If this is not feasible, the condition of the soil itself must be changed to withstand the erosive force of wind.

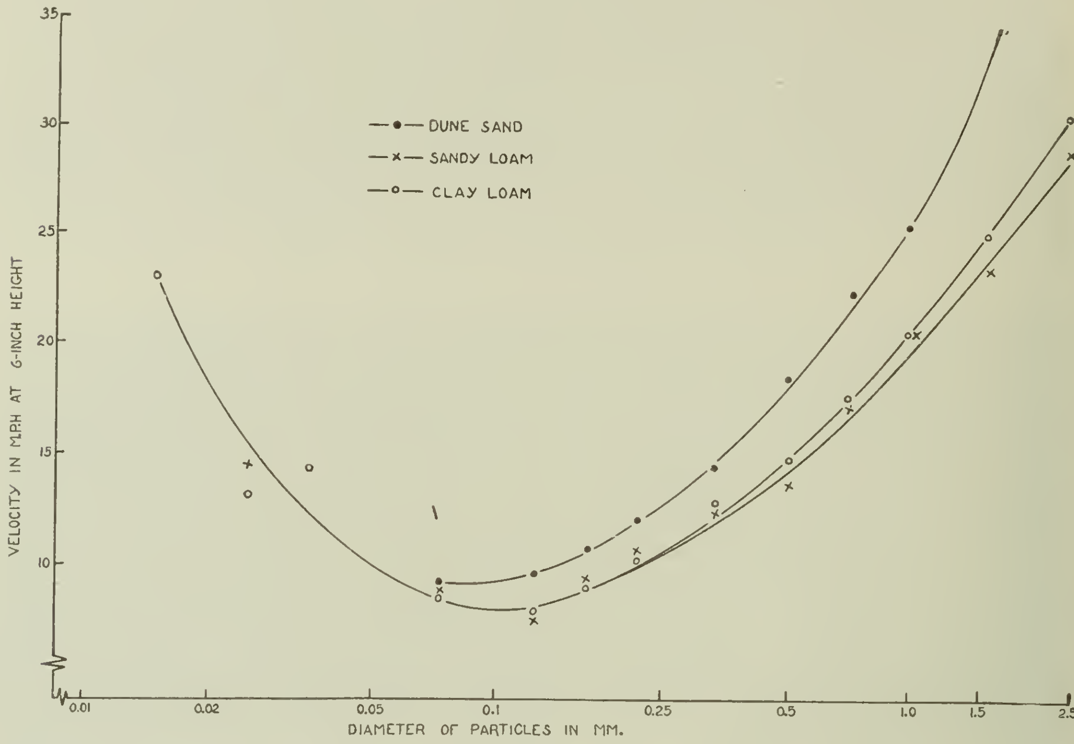


Fig. 17.—Minimum velocities of wind required to initiate and continue the movement of soil particles.

Numerous measurements (9, 10) showed that when soil or sand is composed only of erosive fractions the rate of flow conforms quite well with Bagnold's formula (2) for drifting sand. On cultivated soils comprising both erosive and non-erosive fractions the rate of flow was never constant but changed with duration of exposure, the rate of change depending on the length of the exposed area, the wind velocity, the degree of surface roughness, and the proportion and size of the erosive fractions. The intensity of drifting of cultivated soils in the wind tunnel was rapid at first, but diminished with duration of exposure and ceased after the surface became stabilized with non-erosive fractions. Across narrow strips of fallow in an open field the rate of soil flow was found to decrease with duration of exposure to a continuous wind from one direction, but the reversal of wind direction caused an increase in the intensity of soil drifting. On large areas of fallow, once drifting began it usually increased in intensity, particularly on the leeward side of the drifting field. The increase in the intensity of drifting with duration of exposure was mainly due to an increase in the amount of erosive fractions produced by abrasion of the non-erosive clods and surface crust. The shorter the length of the drifting area the less was the amount of abrasion and hence the lower the rate of flow.

The intensity of drifting under any set of conditions is zero at the windward edge of the exposed field and increases with distance to leeward. On soils containing only erosive particles, such as found in dunes, the distance required for drifting to reach the maximum intensity varies from about 8 to 30 feet,

depending on the roughness of the surface and the size of the particles. On cultivated fields containing both erosive and non-erosive fractions the distance required for drifting to reach the maximum intensity is usually much greater and may be 500 yards or more (19).

Forms of Soil Erosion

The disintegration and movement of soil material by the wind is a complex process involving at least several forms of erosion acting independently and often simultaneously, though in variable degree (18).

The wind acts on the soil in two general ways: by removing loose particles from the surface of the ground by direct pressure and by disintegrating and transporting the soil by force of impacts of wind-borne particles. The different forms of erosion found on cultivated soils are as follows:

Effluxion.—This form of erosion is significant on finely granulated soils, such as highly calcareous clays and fine dune sands, where movement is initiated and maintained by the direct pressure of the wind. The removal is almost entirely by saltation, though small quantities may also be removed by surface creep and some in true suspension.

Extrusion.—This form of erosion occurs on soils that are composed predominantly of fractions too coarse to be removed by direct wind pressure. If, however, a field composed of these fractions is adjoined on the windward by a highly erosive area, erosion may be initiated as a result of bombardment by the smaller particles. Once initiated, erosion of the originally coarse material usually continues even without the bombarding action of particles coming in from adjacent fields.

Detrusion.—Much of the erosion on fields recently cultivated takes place on projections where wind is of a higher velocity than over a smooth surface. Because of high velocity, soil fractions too coarse to be moved along a smooth surface may be dislodged from the crests of projections, such as ridges, and moved into the lee depressions. This form of erosion is particularly common on a surface that has been ridged as with a cultivator and is most serious on granulated soils.

Efflation.—This form of erosion involved the removal of fine soil fractions capable of being transported in true suspension. Efflation is possible only if there is movement of particles in saltation. It is the most serious form of erosion because it produces a gradual coarsening of the soil and an ultimate removal of the most valuable soil fractions—silt and clay.

Abrasion.—The wearing away of soil clods and other indurated soil materials under the cutting action of wind-borne particles is known as abrasion. This form of erosion is particularly serious on loosely held clods and surface crust, such as those formed on sandy loam, and is particularly prevalent on the leeward side of the fields where the quantity of soil transported is the greatest. Abrasion is mainly the consequence of movement in saltation and varies more or less directly with it.

All, or some, of the above forms of erosion may affect the soil simultaneously, but none of the other forms occurs on any appreciable scale without effluxion. Therefore, prevention and control of soil drifting should be based mainly in preventing soils from becoming finely granulated—a condition most inducive to erosion by effluxion.

The above brief outline of the dynamics of wind erosion indicates that there are many factors affecting the intensity of erosion of the soil by wind and that the effect of some of these can be modified by various methods.

The Influence of Topography and Degree of Roughness of Surface on Soil Erosion

Measurements of wind velocity in an area with a rough topography indicated definite lowering of wind velocity for some distances above the surface of depressions and a more definite sheltering effect to leeward of knolls. There was a gradual decrease in velocity up to a height of at least one foot, beginning at the leeward of the crest of a knoll and continuing until the minimum was reached, and then a gradual increase. The greater the slope the greater was the sheltering effect to leeward of knolls, although even in a rolling country, the lines of equal wind velocity tended to conform more or less to the varying slope of the land. Fig. 18 shows the lines of equal velocity over three different degrees of roughness of topography. The data seem to indicate that the increased soil drifting on knolls is due to the increase in velocity of the wind for some distance above the ground surface and to the greater increase of velocity with height.

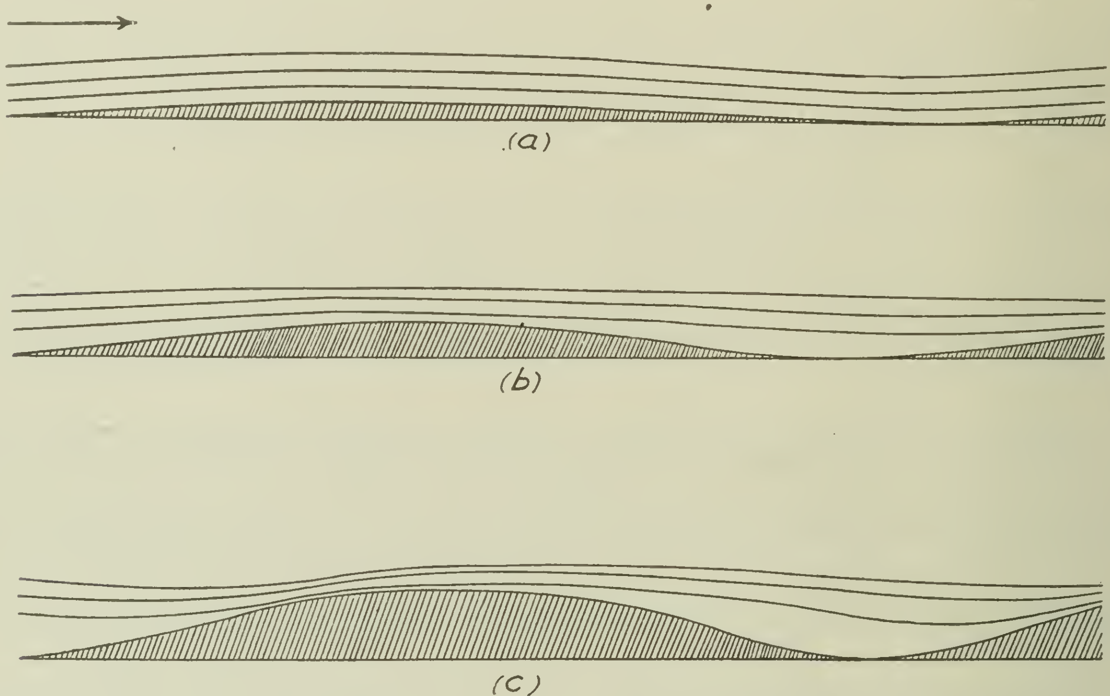


Fig. 18.—Lines of equal wind velocity over *(a)* a change of elevation of 1·5 feet in 100; *(b)* a knoll with a slope of 3 feet in 100, and *(c)* a knoll with a slope of 6 feet in 100. Wind velocity 35 to 40 m.p.h. at a height of 50 feet.

It was previously indicated that the velocity of the wind near the ground is influenced almost entirely by the nature and the degree of roughness of surface. It has also been pointed out that soil drifting depends largely on the wind velocity up to about 18 inches or more, hence any cultural method tending to reduce the surface velocity will tend to reduce soil drifting. Ridging land, as with a duckfoot cultivator or a lister, has been recognized as a useful practice for soil drifting control on most soils, yet some doubt has been expressed on the grounds that, in some cases, ridging may cause an increase in wind turbulence and tend to increase, rather than decrease, the erosion of the soil. A detailed study (10) showed that the erosiveness of a ridged surface is considerably less than of a smooth surface, the actual difference varying somewhat with soil type. Although there is greater turbulence of wind over a ridged surface, the effect of this condition is more than offset by the reduced average velocity of the wind and the trapping of the soil by the furrows. The beneficial effect of heavy floating of land, as practised to some extent on clay soil, is evidently due, not to the decrease in turbulence of wind, but to a change in the physical condition of the soil.

Further investigations (14) showed that short straw worked into the ground surface markedly reduced the velocity of the wind near the ground, whereas the combined action of the straw and ridges reduced the velocity still more. The relative amounts of eroded soil, with one exception, varied more or less proportionately with the average surface velocity of the wind. In Fig. 19 it is shown that the velocity of the wind near the ground was highest over a smooth ground surface (curve *a*) and lowest over a ridged, trashy surface (curve *d*), and that the amount of eroded soil was in direct proportion to velocity.

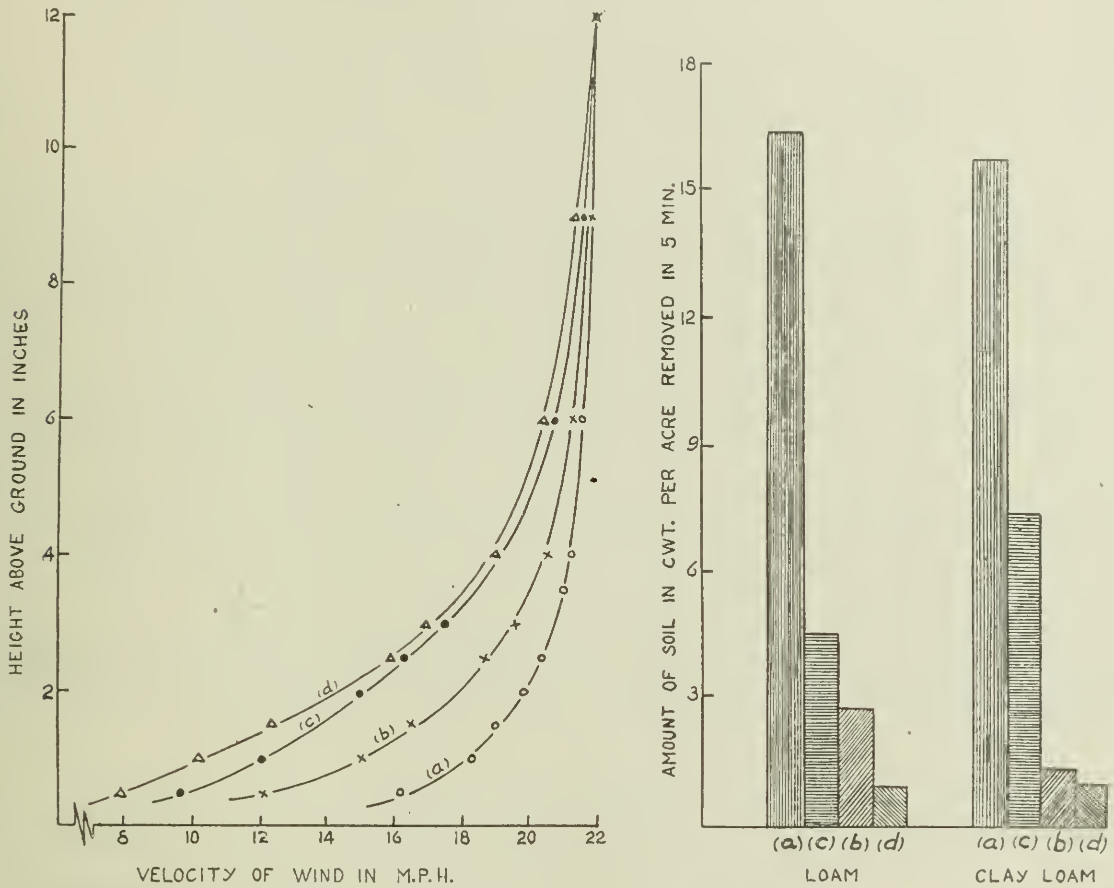


Fig. 19.—Wind velocities at various heights above ground and amounts soil eroded off *(a)* smooth bare ground; *(b)* same as *(a)* with 0·5 ton of short straw worked into the surface; *(c)* ridges 1·25 inches high, 7 inches wide at right angles to the wind, and *(d)* ridges as in *(c)* with straw as in *(b)*.

However, the average velocity over a level, trashy surface (curve *b*) was higher than over ridged surface (curve *c*), yet the amount of erosion was greater over the ridged surface. Although the addition of short straw to the surface of the ground was more effective than ridging, in reducing erosion, this was not altogether due to the reduction of wind velocity but more particularly to the greater capacity of the straw to trap the moving soil. There was found to be appreciably less eddying of the wind over a smooth, trashy surface than over a ridged one.

Crop Residue for Soil Erosion Control

The beneficial influence of crop residue for erosion control is well recognized. The purpose of the investigation reported herewith was to obtain detailed information on the actual reduction produced by different types and quantities of residue incorporated into the soil.

The intensity of erosion was found to be reduced most markedly by the first increment of organic residue, such as straw or stubble, added to the soil, but additional amounts were proportionately less and less effective.

Laboratory results have shown (14) that wind erosiveness q_2 varies roughly as

$$q_2 = \text{antilog}_{10}\,(q_1 - 1{\cdot}2y\sqrt{0{\cdot}3h})$$

where q_1 is the logarithm of erosiveness of the soil without any protective cover and which can be determined from dry sieving procedure described later in this publication, y is the amount of wheat straw and stubble in tons per acre above the ground, and h the average height of trash cover in inches. The above constants are based on an average wind velocity of 22 m.p.h. at 1 foot height, a smooth ground surface, and a combine wheat stubble with the straw spread uniformly and anchored to the soil sufficiently so as not to be moved by the wind. Observations show that erosiveness q_2 having a value less than 0·1 may be considered negligible for all practical purposes.

On moderately to highly erosive soils the amount of erosion was reduced to a negligible factor by 1 to 4 tons of crop residue per acre. The actual amount of crop residue required to reduce drifting to negligible proportions varied with factors such as the erosiveness of the soil, wind velocity, the structure and the moisture content of the soil, the degree of burial of crop residue, the degree of roughness of soil surface, and the nature of the crop residue available.

Table 23 shows the effect of different amounts of straw on the erosiveness of widely different soils. The experiments showed that under a moderate to highwind velocity about 0·25 ton per acre of 6-inch long straw was sufficient to practically eliminate drifting of a slightly erosive soil, 1 ton per acre was required for a moderately susceptible soil, 3 tons per acre for a highly erosive soil, and at least 4 tons per acre for the most erosive dune material. The greater the erosiveness of the soil the greater was the quantity of crop residue required for equal protection. Also, the higher the velocity of the wind, the greater was the amount of crop residue required. The amount of crop residue to withstand a 22 m.p.h. wind at one foot height was about twice that needed to withstand a 17 m.p.h. wind.

TABLE 23.—THE EFFECT OF AMOUNT OF STRAW ON SOIL DRIFTING

Relative erosiveness of soil	Wind velocity at 12-inch height	Amount of soil in tons per acre eroded in 3 minutes						
		No straw	0·25 ton per acre	0·5 ton per acre	1 ton per acre	2 tons per acre	3 tons per acre	4 tons per acre
	m.p.h.							
Resistant	17	Trace						
	22	0·56	Trace					
Moderately erosive	17	0·29	0·35	0·19	0·03			
	22	0·93	0·48	0·24	0·16			
Highly erosive	17	2·56	1·20	0·67	0·51	0·02	0·03	
	22	5·35	3·40	3·09	1·26	0·54	0·03	
Very highly erosive (as dunes)	17	24·35	10·70	5·42	2·59	0·40	0·29	0·13
	22	49·45	25·00	15·05	9·43	3·01	0·93	0·22

A short stubble was found to afford less protection to soil than an equal quantity of longer stubble (Table 24). This is due to the fact that longer stubble, or straw, reaches higher into the air, thus causing a greater reduction of wind velocity near the ground. Cutting a crop as high as possible increases the protective capacity of each unit amount of stubble.

TABLE 24.—THE EFFECT OF LENGTH OF STUBBLE ON SOIL DRIFTING

Length of stubble Inches	Wind in m.p.h. at 12-inch height	Amount of soil in tons per acre eroded when stubble was applied at		
		0·25 ton per acre	0·5 ton per acre	1 ton per acre
2	17	22·6	10·9	3·3
6	17	13·3	6·0	2·7
2	22	84·0	61·4	22·8
6	22	64·7	53·4	13·9
2	27	228·0	170·0	145·0
6	27	174·0	156·0	95·7

When stubble is buried, as with a plough, its protective value is lost and clods and ridges must be depended upon to prevent drifting. The data in Table 25 show the effect of different quantities of stubble mixed uniformly throughout a 2-inch layer of surface soil, as compared with that in which the stubble was merely anchored in the soil—a condition comparable with that produced by any type of blade implement. The average increase in the intensity of erosion as a result of greater burial of the stubble amounted in this case to approximately 20 per cent.

TABLE 25.—THE EFFECT OF DEGREE OF BURIAL OF STUBBLE ON SOIL DRIFTING

Amount of stubble and method of application	Amount of soil eroded in tons per acre			
	Hatton fine sandy loam		Fox Valley silty clay loam	
	17–m.p.h. wind	22–m.p.h. wind	17–m.p.h. wind	22–m.p.h. wind
None	0·70	3·18	0·48	1·59
0·25 ton, uniformly mixed with 2-inch depth of soil	0·59	2·40	0·29	1·26
0·25 ton, anchored*	0·45	2·20	0·19	0·83
0·5 ton, uniformly mixed with 2-inch depth of soil	0·18	1·02		
0·5 ton, anchored*	0·14	0·77		

* Eight-inch stubble was anchored by pushing it down to 2-inch depth at an agle of 45 degrees with the wind.

The type of crop residue is likewise of considerable importance in the control of soil drifting. Stubble was found to be more effective than straw, because the crowns are heavier and less subject to removal by wind. Weeds, particularly young seedlings, are subject to a more rapid rate of disintegration than straw and are therefore less effective in overcoming drifting.

The investigations on the influence of crop residue for soil drifting control indicated that even small quantities of straw and stubble are valuable in greatly reducing the amount of damage that may otherwise occur. The widespread adoption of the ploughless fallow whereby crop residues are retained at the surface of the ground appears to be one of the most important soil conservation developments in recent years.

The use of tillage machines that leave crop residues at the surface of the ground, is, of course, limited by the amount of residue available. In the semi-arid areas of Western Canada, dry years occur when insufficient amounts of residue are available for adequate protection. The use of crop residues should therefore be made in combination with other practices, such as strip farming and the maintenance of a cloddy and ridged soil condition.

Strip Farming for Soil Erosion Control

The intensity of drifting at the windward edge of an eroding field is approximately zero, but increases gradually for a distance of 200 to 500 yards or more, depending on the condition of the soil. The reduction in wind velocity caused by the sheltering effect of the standing stubble extends only 20 to 40 yards, depending on the velocity of the wind and the nature of the stubble. Measurements (9) showed that with a high wind the reduction in velocity at a 10-inch height near the stubble amounted to about 3 miles per hour, but diminished with distance away from the stubble strip, reaching an approximate zero at 20 to 40 yards. The data indicated clearly that the value of stubble strips is not so much the protection of the adjacent fallow from the wind as the trapping of the moving soil, whereby the cumulative intensity of erosion is reduced.

The gradual increase in the intensity of soil drifting toward the leeward side of eroding fields or strips was found (19) to be due to three main factors; the progressive accumulation of erosion particles toward the leeward side of the areas; the cumulative degree of abrasion of the non-erosive fractions resulting from impacts of erosive particles; and the gradual decrease in surface roughness resulting from the levelling-down process caused by erosion.

The rate of change in the intensity of erosion at different lateral positions across eroding fields was found to vary widely, depending on soil type. As shown by typical data in Fig. 20 the rate of increase on loam soil was approximately uniform for a distance of 450 yards or more. The rate of increase on heavy clay was very rapid at first but diminished with distance from the windward edge. At a distance of 100 yards to leeward the intensity of erosion on loam and clay loam was 18·7 and 26·7 per cent, respectively, of the maximum intensity found near the leeward side of the exposed field, but on heavy clay it was 63·0 per cent at the same distance to leeward. Due to the lack of large fields of fallow of highly erosive fine sandy loam, no data were obtainable for a distance greater than 100 yards.

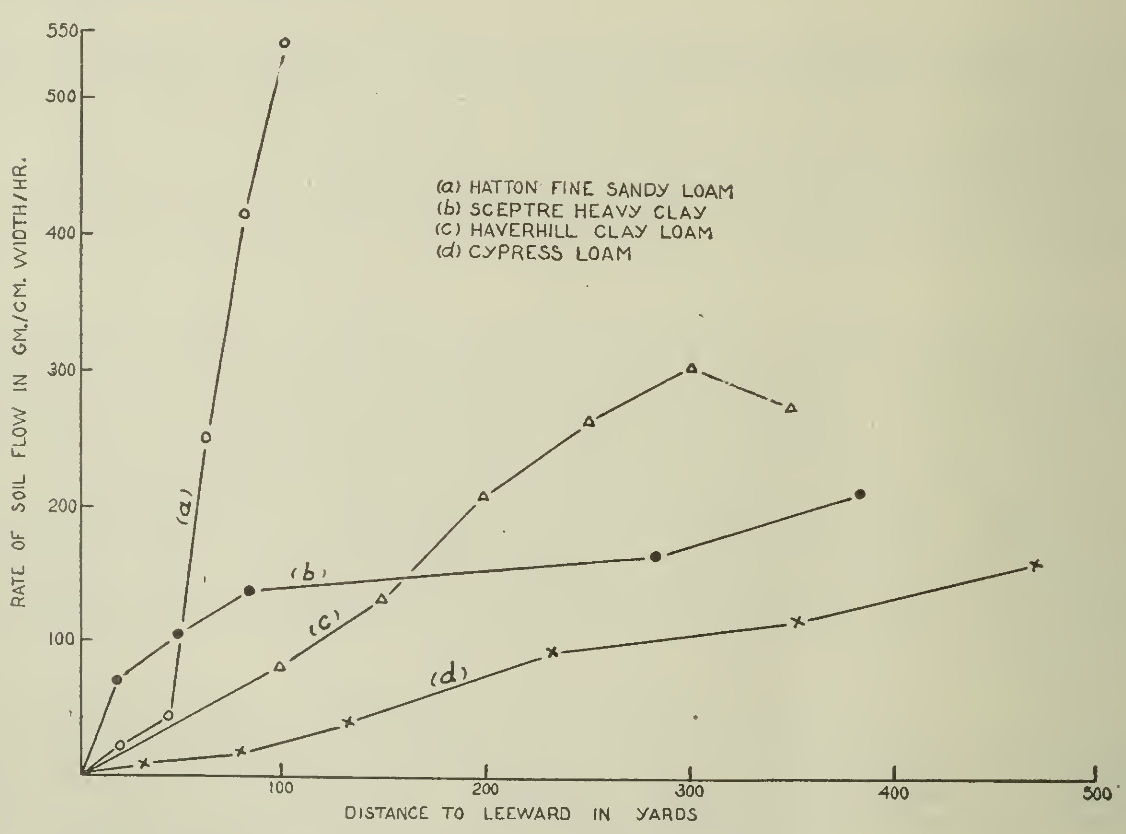


Fig. 20.—The intensity of soil drifting at different distances across eroding fields.

The relatively rapid increase of intensity of drifting near the windward edge of fields of heavy clay appears to be due, mainly, to a relatively thick layer of erosive particles which continue to erode at a fairly rapid rate even after relatively long exposure to the wind. Except at the extreme windward edge, the rate of soil flow is, more or less, the same across the whole field.

Loam and clay loam have less erosive particles on the surface, so that there is a tendency for complete removal of erosive fractions from the windward side—the closer the distance to windward the greater is the extent of removal and hence the lower the rate of flow. On soils of this class there is a gradual accumulation of erosive particles towards the leeward side of a field and it is this type of accumulation that is directly associated with the intensity of soil flow.

The cumulative intensity of erosion across wind-eroded fields has a direct bearing on the relative usefulness of strip farming on different soils. As shown in Fig. 20 the intensity of drifting on the leeward side of a 20-rod fallow strip of loam, clay loam and clay was approximately 18·7, 26·7, and 63·0 per cent of the possible maximum intensity that would be found on the leeward side of a field if it was not divided into strips. The data indicate that strip farming would be less effective on clay than on loam and clay loam soils. This conclusion has been substantiated by general experience in field practice.

Due to the highly erosive nature of the majority of sandy soils, strips of fallow must be much narrower than on other soils to be equally effective and may have to be so narrow as to be impractical in many ways. Under severe conditions, a complete vegetative cover of the ground appears at present to be the only solution.

The Relation of Clod Structure to Soil Erosion

Factors affecting the intensity of erosion of soil composed of erosive fractions only, such as found in freshly accumulated drifts or dunes, have been indicated in previous sections of this report. Cultivated soils are seldom composed of erosive fractions only but are made up of fractions of a wide range of size, the larger of which are non-erosive and give a certain amount of protection to smaller, erosive grains.

The experiments conducted in the wind tunnel on the erosiveness of cultivated soils (8, 11) showed that the approximate erosiveness, q, on a level surface under the usual range of erosive wind velocity can be determined by the formula:

$$q = \text{antilog}\left[\frac{0\cdot 75C + 1\cdot 14D + 1\cdot 49E + 1\cdot 80F}{C+D+E+F} - 0\cdot 5\frac{B}{A+B} - 0\cdot 42(C+D+E+F)\right]$$

where A – per cent erosive fraction $< 0\cdot 42$ mm. in diameter,

B – per cent erosive fraction $0\cdot 42$–$0\cdot 83$ mm. in diameter,

C – per cent non-erosive fraction $0\cdot 83$–$2\cdot 0$ mm. in diameter,

D – per cent non-erosive fraction $2\cdot 0$–$6\cdot 4$ mm. in diameter,

E – per cent non-erosive fraction $6\cdot 4$–$12\cdot 7$ mm. in diameter,

F – per cent non-erosive fraction $> 12\cdot 7$ mm. in diameter.

To determine the erosiveness of any soil it is necessary to sieve it in a thoroughly air-dry state, determine the percentage of each of the different sizes of soil particles, and compute the erosiveness according to the above formula. Short-cut tables have been prepared to facilitate the computations. Comparisons between determined and computed erosiveness of many samples

showed that the formula can be used as an approximate measure of erosiveness of different soils. It was found to apply somewhat more accurately to soils that have been recently cultivated than to soils that have lain uncultivated for some time or have formed a surface crust following a rain (11). The highly erosive soils were observed to have an erosion value q greater than 1, whereas the resistant to moderately erosive soils had an erosion value of less than 1. Soils with q less than $0 \cdot 1$ may be considered highly resistant to wind erosion.

In determining the clod structure of any soil, it is essential that a uniform and accurate procedure be followed in all sieving analyses. A rotary sieve eliminating the inconsistent results of older methods of sieving has been devised for this purpose (13).

The results of experiments showed that the greatest degree of protection to the erosive particles A and B is offered by fractions ranging from approximately 1 to 6 mm. in diameter, i.e., by those not finer than fine gravel and not appreciably larger than a pea. The data show that it is possible to eliminate drifting with any size of non-erosive fractions, provided the quantity of these is high enough. To be wholly resistant to wind erosion, about one-half of the weight of the soil should be composed of the smaller non-erosive fractions, such as C and D when the other half is composed of highly erosive particles, or at least two-thirds of the weight of the soil to be composed of large clods when the other third is composed of the highly erosive particles.

Fraction B which ranges from approximately $0 \cdot 5$ to 1 mm. in diameter erodes only with difficulty. When fraction A, mixed with any quantity of the non-erosive fractions is replaced by B, the erosiveness of the soil is decreased on the average by about 75 per cent. An increase of coarse, semi-erosive granules, such as B, will in most cases markedly reduce the erosiveness of the soil.

A striking feature of the results obtained is the existence of a logarithmic relation between erosiveness and the amount of non-erosive fractions present in the soil (8). Consequently, the erosiveness of a soil is reduced most markedly by the first increment of the non-erosive fractions added, but each succeeding increment becomes less and less effective.

Properties of Soil Influencing Erosion

The clod structure, and consequently the erosiveness of a soil, was found to be influenced not by any single factor but by a number of factors, the nature and the relative influence of which vary widely in different soils. An evaluation of wind erosiveness of soils involves the effect of the following major factors: the amount of water-stable aggregates greater than $0 \cdot 5$ mm. in diameter; the relative quantity of water-stable particles less than $0 \cdot 05$ mm. and particularly less than $0 \cdot 02$ mm. in diameter; texture; the amount of calcium carbonate; and the nature and the amount of organic matter. The dry clod structure, as determined by sieving, serves as an approximate index of the combined effect of all of these major factors.

The Effect of Water-stable Aggregates

Highly erosive soils contain relatively large amounts of water-stable aggregates $0 \cdot 05$ to $0 \cdot 5$ mm. in diameter, whereas resistant soils are characterized by relatively large amounts of aggregates greater than $0 \cdot 5$ mm. in diameter and also by relatively large quantities of water-stable aggregates smaller than $0 \cdot 02$ mm. in diameter (12). The marked influence of fractions greater than $0 \cdot 42$ mm. in diameter in reducing the erosiveness of the soil is indicated in Table 26. The soils shown are alike in every respect but differ only in the size and quantity of fractions greater than $0 \cdot 42$ mm. The data indicate that the larger the size of the water-stable aggregates and the greater the quantity of these, the greater is the increase in cloddiness and decrease in erosiveness of the soil.

TABLE 26.—RELATION BETWEEN THE WATER-STABLE AGGREGATES >0·42 mm. IN DIAMETER, THE DRY CLOD STRUCTURE, AND THE WIND EROSIVENESS OF SOILS

Soil class	M. equiv.	Org. matter	Water-stable aggregates							Dry clod distribution							Amount eroded in 18 min.
			>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25–0·05	0·05 0·02	<0·02 mm.	>38·0 mm.	38·0–12·7	12·7–6·4	6·4–2·0	2·0–0·83	0·83–0·42	<0·42 mm.	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	tons/acre
Clay.........	38·2	2·09	0·0	0·0	0·0	29·2	52·8	13·5	4·5	0·0	3·0	3·0	1·1	0·2	3·2	89·5	41·75
	37·9	2·11	0·0	0·0	12·1	31·0	39·4	12·9	4·6	0·0	1·5	3·7	4·2	4·2	22·9	63·5	16·90
	38·4	2·09	0·0	0·7	23·4	31·6	26·7	13·1	4·5	0·0	3·2	3·0	7·2	10·5	19·2	56·9	4·36
	37·5	2·10	0·0	1·3	36·6	23·9	20·0	13·7	4·5	0·0	11·9	5·4	13·2	19·7	29·7	20·1	1·04
	36·1	2·12	0·0	25·6	28·4	16·3	11·9	13·2	4·6	5·4	6·0	1·6	6·6	58·5	11·9	10·0	−0·24*
Loam........	21·0	1·11	0·0	0·0	0·7	18·3	61·7	15·2	4·1	0·0	2·0	11·6	3·2	3·9	13·2	66·1	10·15
	20·3	1·13	0·0	1·0	16·5	25·8	37·4	14·7	4·6	0·0	2·9	9·8	4·1	5·1	21·0	57·1	7·83
	20·5	1·11	0·0	2·1	31·3	20·5	27·4	14·6	4·0	0·0	6·0	10·8	3·9	4·1	27·0	48·2	6·09
	19·7	1·12	0·0	7·3	37·8	17·6	17·7	15·2	4·4	0·0	2·7	9·1	7·9	15·4	21·8	43·1	1·33
Fine sandy loam.......	9·7	1·10	0·0	0·0	0·0	3·9	89·6	5·5	1·0	0·0	0·0	0·0	0·0	0·3	1·6	98·1	107·00
	8·9	1·10	0·0	0·0	8·5	4·9	80·6	5·0	1·0	0·0	0·0	0·0	0·0	0·8	12·5	86·7	105·30
	8·1	1·10	0·0	0·0	15·2	5·7	73·0	5·0	1·1	0·0	0·0	0·0	0·0	0·4	20·5	79·1	81·01
	8·8	1·09	0·0	8·6	1·5	3·5	80·2	5·2	1·0	0·0	0·0	4·0	0·0	6·9	17·6	71·5	31·39
	7·7	1·09	0·0	6·2	14·6	5·4	68·2	4·5	1·1	0·0	0·0	3·9	0·2	10·4	2·0	83·5	23·21

* A minus sign indicates greater accumulation than removal of the incoming soil.

TABLE 27.—RELATION BETWEEN THE WATER-STABLE PARTICLES <0·05 mm. IN DIAMETER, THE DRY CLOD STRUCTURE, AND WIND EROSIVENESS OF DIFFERENT SOILS

Soil class	M. equiv.	Org. matter	Water-stable aggregates							Dry clod distribution							Amount eroded in 18 min.
			>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25–0·05	0·05 0·02	<0·02 mm.	>38·0 mm.	38·0–12·7	12·7–6·4	6·4–2·0	2·0–0·83	0·83–0·42	<0·42 mm.	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	tons/acre
Clay.........	40·1	2·50	0·0	1·2	21·4	28·1	31·7	10·0	7·6	0·0	0·0	1·3	4·9	6·6	35·8	51·4	18·98
	37·0	2·48	0·0	1·3	21·3	23·4	28·3	14·1	11·6	2·3	23·4	17·8	14·0	3·8	19·8	18·9	4·31
	39·6	2·48	0·0	1·3	17·7	19·8	29·4	17·0	14·8	0·0	48·0	24·4	10·5	2·5	6·8	7·8	−0·56
	38·0	2·50	0·0	0·8	19·8	19·0	21·2	20·5	18·7	24·3	39·9	25·5	6·5	0·6	0·7	2·5	−1·61
Loam........	21·0	1·73	0·0	0·0	3·1	5·7	77·8	11·5	1·9	0·0	0·0	0·0	0·5	0·9	22·8	75·8	96·10
	21·2	1·74	0·0	0·0	2·8	4·8	70·5	14·8	7·1	0·0	0·0	0·0	0·8	6·9	16·7	75·6	40·60
	21·4	1·73	0·0	0·0	3·7	2·8	63·7	16·9	12·9	0·0	25·1	7·7	5·2	1·6	6·0	54·4	11·11
	21·5	1·74	0·0	0·0	3·9	2·5	54·5	21·4	17·7	2·3	40·2	7·4	6·1	4·5	1·4	38·1	3·66
Fine sandy loam.......	8·2	1·23	0·0	0·0	1·2	4·4	86·4	4·0	0·0	0·0	0·0	0·0	0·0	0·0	1·0	99·0	157·30
	9·9	1·25	0·0	0·0	1·4	2·1	82·4	9·1	5·0	0·0	10·6	2·2	5·9	1·9	1·6	77·8	51·65
	12·1	1·25	0·0	0·0	0·9	1·3	72·8	13·9	11·1	2·5	16·1	6·1	6·6	1·7	7·1	59·9	13·62
	14·5	1·27	0·0	0·0	1·0	0·5	63·8	19·1	15·6	11·3	27·0	7·3	7·5	2·2	1·2	43·2	5·68

Furthermore, the data in Table 27 show that as the quantity of the water-stable particles smaller than 0·05 mm., and particularly smaller than 0·02 mm. in diameter, increases, there is a corresponding increase in cloddiness and a consequent decrease in erosiveness. The initial increments of these fine particles reduce the erosiveness very appreciably but each subsequent increment becomes less effective. It was found that the water-stable aggregates 0·02 to 0·05 mm. in diameter increase the cloddiness and decreased the erosiveness to some extent, but compared with particles smaller than 0·02 mm., their effect was practically insignificant.

The Effect of Soil Texture

Soil texture is another factor that influences wind erosion to a marked extent. Many clay soils are highly susceptible to erosion on account of the marked disintegration of clods as a result of swelling and contracting under the influence of the weather. On the other hand, sandy soils are highly susceptible, due to limited amounts of cementing substances necessary to hold the sand grains together and to the fact that weakly cemented clods are readily abraded by wind-borne grains. As the fineness of soil texture is indicated quite accurately by the moisture equivalent, it would seem feasible to use the moisture equivalent as an index of the erosiveness of the soil. The erosiveness is least for soils with a moisture equivalent of about 23, but increases as the moisture equivalent deviates above or below this value (7). The moisture equivalent for a medium sandy loam is approximately 15, for loam 22, and a heavy clay 40. Other factors being equal, clay and sandy soils are therefore more erosive than loam and clay loam soils.

The size of individual particles composing the soil also has a marked influence on wind erosion. As shown in Table 28, the threshold velocity required to produce a continuous soil movement, is least for particles of 0·1 to 0·5 mm. in diameter, but for particles below this size the threshold velocity increases with a decrease in the size. Loose silt particles (0·005 to 0·01 mm.) were found to be very resistant to wind erosion and did not move even under a wind velocity of 37 miles per hour at 6-inch height. Particles smaller than 0·005 mm. do not exist as such in ordinary soil, for they are aggregated into larger individual granules.

TABLE 28.—FLUID THRESHOLD WIND VELOCITIES FOR LOOSE, DRY QUARTZ PARTICLES*

Size of particles	Specific gravity	Threshold velocity
mm.		m.p.h.
0·005–0·01	2·65	>37·0
0·01 –0·02	2·65	23·0
0·02 –0·05	2·65	14·4
0·05 –0·10	2·65	9·2
0·10 –0·15	2·65	8·5
0·15 –0·25	2·65	11·1

* Wind velocity at 6-inch height. Length of exposed area 3 feet.

The high resistance of fine silt particles to erosion by wind is due, partly, to cohesion between the individual particles (16), but more particularly to the fact that the particles do not protrude above the more or less viscous layer of

air close to the surface of the ground. In addition to being extremely resistant to wind erosion, individual silt particles less than 0·02 mm. in diameter were found to have no abrasive action, but when blown with the wind, stuck to the surface of the clods and other obstructions. As indicated previously, an increase in the quantity of particles less than 0·02 mm. in diameter causes a corresponding increase in cloddiness and decrease in wind-erosiveness of soils.

The susceptibility of dry soil blocks to abrasion by wind-borne grains of sand varied directly with their cohesive strength (Table 29). However, the high cohesive property of clay in a dry state and the high resistance of the dry blocks of clay to abrasion is not an indication of their resistance to wind erosion, for clay lumps crack excessively under the influence of the weather, in many cases disintegrating into granules too small to resist the erosive force of wind. Clods composed of fine silt do not granulate but, on drying, remain as a compact mass which resists abrasion to a moderate degree. Fine sand grains, on the other hand, have no cohesive property, whereas coarse silt (0·02–0·05 mm.) possesses characteristics intermediate between the two.

TABLE 29.—COHESIVE STRENGTH OF DRY BLOCKS COMPOSED OF DIFFERENT SIZES OF SOIL PARTICLES AND THEIR SUSCEPTIBILITY TO ABRASION BY FINE SAND

Size of particles	Weight required to crush cylindrical blocks 0·5 x 0·5 inch	Amount abraded per 12·8 grams of abrasor per minute*
mm.	gm	gm.
Ca-clay <0·005	54,225	T
H-clay <0·005	44,200	T
Na-clay <0·005	37,850	T
Quartz 0·005–0·01	2,023	1·0
Quartz 0·01–0·02	117	8·0
Quartz 0·02–0·05	28	34·3
Quartz 0·05–0·10	T†	—

† Crumbled on slight touch.
* 22-m.p.h. wind.

A certain proportion of clay seems to be essential for the greatest stability of the soil against the wind, but a clay content of 20 per cent or over may be detrimental in that it may cause the formation of small granules similar in erosiveness to dune sand. Calcareous clays, in particular, disintegrate into granules too small to resist the wind. On the other hand, loams and sandy loams often erode as a result of abrasion by loose sand blown in by the wind. A small quantity of loose sand grains passing over a sandy loam or loam is often sufficient to wear down a surface crust and expose the more highly erosive soil beneath. Once the protective surface crust is removed, the erosion of the soil continues even without the aid of the abrasor.

The clay soils investigated seldom have a surface crust but may be resistant to erosion because of their high content of coarse, non-erosive aggregates. Under the action of freezing and thawing, wetting and drying, as in the early spring, these non-erosive fractions often slake down to highly erosive granules. The soil will then drift irrespective of whether there is an incoming flow of material or not. This is evidently the reason why drifting on clay soil is often more or less spontaneous over the whole field, whereas on loam and sandy loam it usually

starts at some highly erosive spot and extends fan-wise to leeward as the surface crust protecting the soil is worn through by the incoming material.

The spread of soil drifting, particularly on coarse and medium-textured soils, is often caused by some spot serving as a source of supply of highly erosive material, such as may be found on knolls or dunes. Complete protection of such spots is a prerequisite to the successful control of drifting in the rest of the field.

The Influence of Calcium Carbonate

Calcium carbonate increases the erosiveness of a soil very considerably in most cases. The data in Table 30 show that there is a marked decrease in cloddiness and consequent increase in erosiveness as a result of adding different amounts of finely ground calcium carbonate. The effect was greater on Haverhill loam than on Sceptre heavy clay and Hatton fine sandy loam. This may be partly due to the fact that the original amount of calcium carbonate was lower in Haverhill loam than in the other soils. The erosiveness of Sceptre heavy clay and Haverhill loam increased more or less in proportion to the amount of calcium carbonate they contained, but the erosiveness of Hatton fine sandy loam was highest when the calcium carbonate content was about 2·5 per cent and decreased as the amount of calcium carbonate deviated above or below this value.

The addition of calcium carbonate to soil decreased the proportion of the water-stable aggregates smaller than 0·02 mm. in diameter but, with the exception of Hatton fine sandy loam, it had practically no effect on the other sizes. The application of calcium carbonate to Hatton fine sandy loam in amounts greater than 5 per cent somewhat increased the quantity of coarse water-stable aggregates. The effect on the water-stable structure was slight compared with its effect on the dry clod structure. It is apparent that calcium carbonate influences soil drifting more by the change it produces in the state and strength of the secondary aggregates, or clods, than in the primary water-stable aggregates. The reduction in quantity of the water-stable aggregates smaller than 0·02 mm. may weaken the bonds that hold these aggregates together when forming clods.

The greater erosiveness of knolls, as compared with other areas of a field, can be attributed not only to greater wind velocity and turbulence but also to a higher amount of calcium carbonate in the soil. In the semi-arid regions, the soil profile is characterized by a calcium carbonate layer which in a normal, uneroded profile is 10 to 18 inches below the surface, but may be within 3 or 4 inches of the surface on the knolls. As a result of cultivation or wind and water erosion, the calcium carbonate layer may be exposed, thus serving as a source from which this material may be spread to surrounding areas. Such knolls are a serious menace and should be kept permanently in grass.

The Influence of Organic Matter

In a greenhouse experiment, finely ground wheat straw was added to 15 different Saskatchewan soils at the rate of 10 tons per acre in October, 1940, and again in August, 1941. The treated soils and corresponding checks were placed in glazed gallon crocks and moistened at intervals. The straw caused a marked increase in aggregation of all soils, as shown in Table 31. However, this effect was not permanent, for, by September, 1944, the treated and the untreated soils were virtually alike in structure and by September, 1946, the treated brown and dark brown soils contained actually more of the fine wind-erosive particles than the check. This and other experiments carried out, under field conditions, showed that organic matter in the process of decomposition was highly inducive to clod formation and was beneficial in reducing the hazard of soil drifting. Decomposed organic matter causes the formation of granules that are generally too small to resist the wind.

TABLE 30.—THE INFLUENCE OF CALCIUM CARBONATE ON SOIL DRIFTING

Soil type	$CaCO_3$	Water-stable aggregates							Dry clod distribution							Amount eroded in 18 min.
		>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25 0·05	0·05–0·02	<0·02 mm.	>38·0 mm.	38·0–12·7	12·7–6·4	6·4–2·0	2·0–0·83	0·83–0·42	<0·42 mm.	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	tons/acre
Sceptre heavy clay...	0·93	0·2	1·5	14·2	25·3	36·8	12·3	9·7	0·0	0·2	1·8	5·0	18·9	29·6	44·5	26·1
	2·93	0·0	1·9	13·3	24·9	37·1	13·4	9·4	0·0	0·0	1·4	6·4	12·4	25·9	53·9	36·1
	5·93	0·0	1·7	11·8	27·1	39·2	12·1	8·1	0·0	2·5	1·2	3·8	9·0	29·4	54·1	34·9
	10·93	0·0	1·5	17·1	25·9	34·3	13·9	7·3	0·0	0·4	1·1	3·1	9·3	28·8	57·3	43·4
Haverhill loam.......	0·18	1·8	4·1	14·8	12·7	40·9	16·2	9·5	4·4	22·9	7·6	7·1	5·2	10·4	42·4	3·7
	2·18	0·8	3·8	15·9	14·1	38·5	17·0	9·9	0·0	3·2	4·2	9·0	6·5	12·4	64·7	11·7
	5·18	0·0	3·1	13·2	15·8	43·9	15·9	8·1	0·0	0·1	1·7	8·4	7·2	12·9	69·7	24·0
	10·18	0·0	5·9	16·9	13·8	38·9	16·8	7·9	0·0	0·0	1·0	7·2	9·2	16·0	66·6	34·4
Hatton fine sandy loam..............	0·58	5·1	3·8	10·2	8·9	40·2	24·0	7·8	0·0	3·3	3·6	8·8	8·8	10·2	65·3	29·2
	2·58	1·2	4·5	5·9	8·1	51·7	20·8	7·8	0·0	0·2	4·2	8·2	7·0	7·0	73·4	38·9
	5·58	4·0	10·3	5·8	8·7	43·8	22·1	5·3	0·0	0·4	1·4	9·4	7·8	8·3	72·7	36·7
	10·58	7·8	8·9	12·2	9·6	39·4	18·1	4·1	0·0	2·7	2·0	8·1	8·4	9·3	69·5	33·6

TABLE 31.—THE INFLUENCE OF WHEAT STRAW ON SOIL STRUCTURE*

Soil Type	Organic matter, October 1940	Wind erosive particles less than 0·83 mm. in diameter							
		August 1941		September 1942		September 1944		September 1946	
		Straw applied	No straw	Straw applied	No straw	Straw applied	No straw	Straw applied	No straw
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Brown Soils									
Sceptre heavy clay	2·49	25·6	41·6	55·3	56·4	29·4	39·6	36·8	36·8
Fox Valley silty clay loam	3·99	20·9	19·6	61·0	56·4	61·6	38·7	68·4	57·0
Haverhill clay loam	3·51	30·1	44·9	68·5	76·9	68·9	72·9	75·0	70·7
Haverhill loam	3·51	32·4	67·5	84·3	81·9	85·0	87·8	87·4	89·7
Hatton fine sandy loam	3·06	47·3	86·1	87·9	89·7	88·6	91·2	88·8	85·8
Average for brown soils	3·31	31·3	51·9	71·4	72·3	66·7	66·0	71·3	68·0
Dark Brown Soils									
Regina heavy clay	3·53	19·6	25·3	53·7	42·3	36·4	23·4	19·8	17·1
Elstow silty clay loam	4·91	42·3	60·2	78·1	86·5	81·4	80·3	82·5	79·4
Elstow silt loam	4·91	29·5	47·9	79·2	84·0	75·9	75·2	80·9	77·2
Weyburn loam	5·52	45·6	58·9	86·7	89·8	84·4	87·3	87·8	86·1
Asquith fine sandy loam	2·65	60·3	75·3	90·9	92·2	91·4	92·7	92·2	89·2
Average for dark brown soils	4·30	39·5	53·5	77·7	79·0	73·9	71·8	72·6	69·8
Black Soils									
Melfort silty clay loam	9·95	39·6	58·7	67·3	73·3	71·0	77·6	74·2	80·3
Blaine Lake clay loam	6·31	37·8	54·1	75·5	82·2	79·2	79·9	80·0	78·0
Blaine Lake silt loam	7·86	43·9	66·2	81·7	87·9	83·4	90·1	79·8	86·1
Oxbow loam	7·61	47·5	70·0	79·9	83·6	82·1	84·7	83·4	83·7
Melfort fine sandy loam	3·66	48·8	86·4	88·2	95·1	91·4	95·9	94·3	96·6
Average for black soils	7·08	43·5	67·1	78·5	84·4	81·6	85·6	82·3	84·9

* Finely ground wheat straw was applied at the rate of 10 tons per acre in October, 1940, and again in August, 1941. Soil was kept moist and the surface bare.

The high content of decomposed organic matter, or humus, in some soils of Western Canada is inducive to high fertility and good tilth, but facilitates wind erosion, especially on coarse and medium-textured soils. Under identical treatment (Table 31), the black soils contained more wind erosive fractions than the brown or dark brown soils and would be susceptible to wind erosion. Excessive granulation may be partially counteracted by leaving as much crop residue on the ground as possible, which will not only protect the surface from the wind but, as it decomposes, will produce mucilaginous materials that are especially useful in forming wind-resistant clods.

Decomposed humus in one sense is inducive to soil aggregation in that it causes the cementation of individual silt and clay particles into granules that are quite stable in water. These particles are quite resistant to water erosion, but not generally to wind erosion for the size of soil particles readily carried by water is much smaller than that most readily moved by wind. Middleton found (34) that soils susceptible to water erosion contain a higher ratio of dispersed silt and clay (particles smaller than 0·05 mm. in diameter) than soils resistant to water erosion. Another investigation (7) showed that the content of dispersed silt and clay varied inversely with the susceptibility to wind erosion.

Soil Erosion Control on Different Soil Types

Different soil types possess different physical and chemical properties influencing wind erosiveness, and therefore require different methods for erosion control. Soil texture is one of the most important factors.

Work on different major soil types showed that on medium-textured soils, such as on loam, clay loam, and silty clay loam, a ploughed fallow was more conducive to clod formation than a ploughless fallow, but on heavy clay or fine sandy loam there was no appreciable difference (Table 32). These analyses were made in the spring just before the fields were seeded. Although the differences were most marked on the medium-textured soils, these soils are much less erosive than clay and sandy soils, partly because of their readiness to form a highly-resistant surface crust, irrespective of the type of cultural treatment employed.

TABLE 32.—THE INFLUENCE OF PLOUGHED AND PLOUGHLESS FALLOW ON CLODDINESS AND EROSIVENESS OF DIFFERENT SOILS

Soil type	Type of fallow	Size distribution of dry clods to 2·5 inch depth						Wind erosiveness kg./sq. metre
		>38·0 mm.	38·0–12·7	12·7–6·4	6·4–2·0	2·0–0·83	<0·83 mm.	
		per cent	per cent	per cent	per cent	per cent	per cent	
Regina heavy clay	Ploughed	0·0	0·0	0·5	9·2	19·4	70·9	0·23
	Ploughless	0·0	0·0	1·8	7·9	21·9	68·4	0·19
Sceptre clay	Ploughed	0·0	1·6	2·9	4·6	12·1	78·8	0·72
	Ploughless	0·0	0·0	1·0	3·5	6·7	88·8	2·12
Fox Valley silty clay loam.	Ploughed	0·0	11·5	9·3	13·8	14·9	50·5	0·09
	Ploughless	0·0	8·7	6·0	10·3	9·3	65·7	0·44
Haverhill clay loam	Ploughed	3·7	13·2	8·9	8·9	8·5	56·8	0·29
	Ploughless	5·8	9·5	6·7	8·0	6·5	63·5	0·60
Haverhill loam	Ploughed	1·6	30·2	6·5	7·8	6·6	47·3	0·11
	Ploughless	0·1	8·3	4·6	6·8	6·9	73·3	1·23
Haverhill light loam	Ploughed	3·0	10·0	6·5	9·3	5·5	65·7	0·58
	Ploughless	0·0	4·2	3·8	8·7	7·8	75·5	0·93
Hatton find sandy loam.	Ploughed	0·0	0·5	1·1	3·4	12·3	82·7	1·01
	Ploughless	0·0	4·9	3·7	3·7	10·9	76·8	1·32

Ploughing medium-textured soils will have definite advantages in overcoming drifting when insufficient amounts of crop residue are present to give the soil the necessary protection. The question that must be answered is whether the increase in the resistance to drifting produced by ploughing is greater than the protective value of plant residue left at the surface of the ground. There appears to be no advantage in ploughing heavy clay and sandy soils for soil drifting control. Whether medium-textured soils are to be ploughed or not would depend largely on local conditions, but it is necessary to recognize the relative benefits of the increased cloddiness and stubble mulch and to take advantage of one or the other when conditions permit. The greatest possible use of crop residue should be made at all times.

The Effect of Soil Moisture at the Time of Cultivation

The results of field and laboratory experiments showed that the greatest degree of pulverization of medium- and fine-textured soils took place when they were worked in a slightly moistened condition, or at a moisture content of 6 to 9 per cent in loam, and 14 to 18 per cent in clay (Fig. 21). In a thoroughly air dry state they were somewhat more resistant to the pulverizing action of tillage machinery. A definite increase in aggregation took place when these soils were worked in a moist or plastic condition, the degree of aggregation varying directly with the moisture content at the time of tillage. That is, at the lower part of the plastic range, small, weakly cemented granules and lumps were formed, but as the moisture content increased, larger and denser clods were formed.

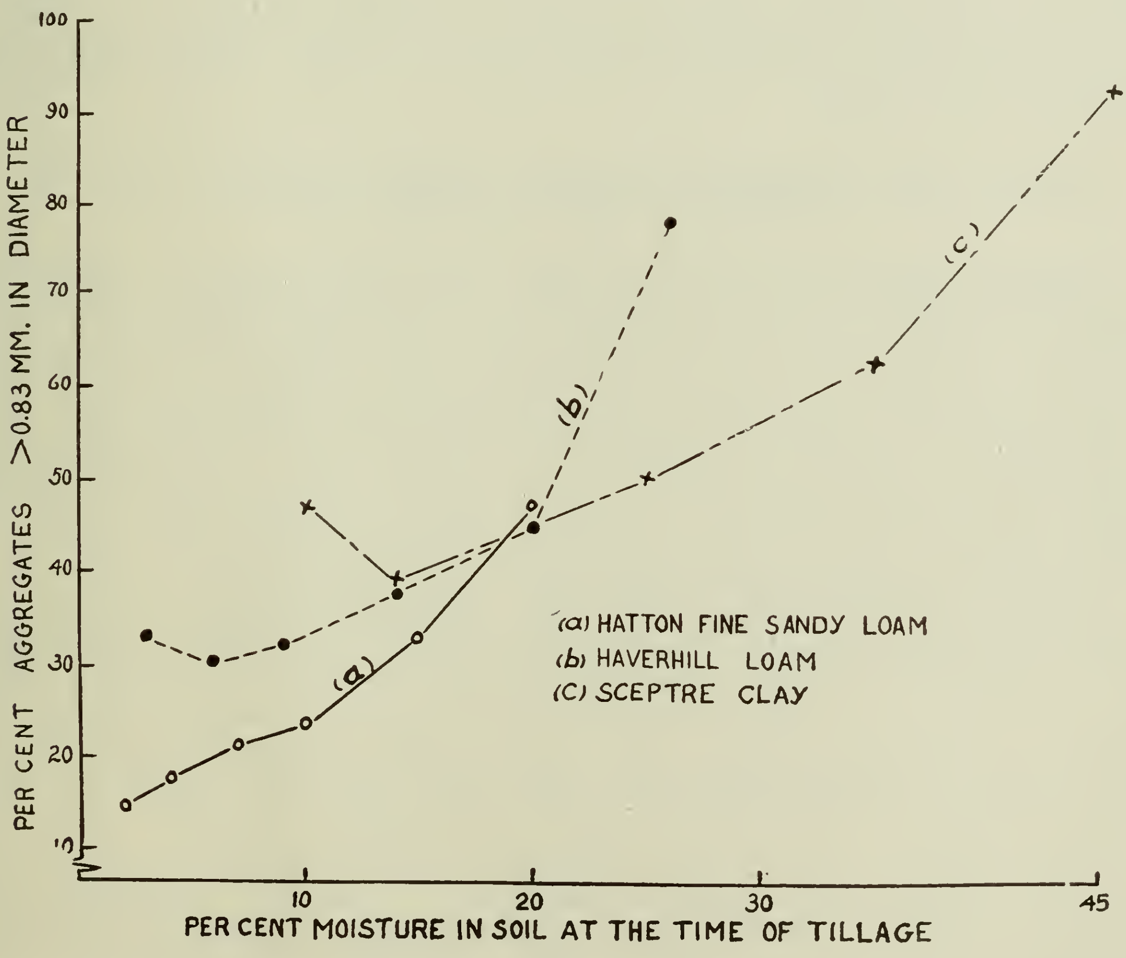


Fig. 21.—The influence of moisture content at the time of tillage on the resultant soil structure.

Sandy soils pulverized most readily at the lowest possible moisture content, but as moisture increased, tillage became more and more effective in increasing the cloddiness of the soil. However, the possible maximum degree of aggregation of a sandy soil was much lower than the possible maximum for loam or clay.

The most favourable structure of the originally pulverized soil was formed when it was tilled at about the sticky point. The moisture at the sticky point for any soil almost coincides with its moisture equivalent and, except for very sandy soil, can be determined with a fair degree of accuracy in the field by testing for stickiness between the fingers.

The higher the moisture content at the time of working, the longer the resultant clods lasted under field conditions. However, there was a marked variation in the rate of disintegration of clods of various soils. Sandy soils disintegrated most readily after puddling. Next in order were, heavy clay, silty clay loam, clay loam, and loam. This coincides more or less with the general wind erosiveness of these soil classes.

A moderate amount of puddling of the semi-arid soils no doubt causes an increase in their resistance to wind erosion and produces no detrimental effect on the yield of grain crop, but the problem is to design implements that can be operated effectively on wet soils. Packing wet soils thoroughly with a heavily weighted surface packer produced greater cloddiness than disking or cultivating, but packing dry soils caused much greater pulverization of the surface soil.

The results indicated that tillage of most soils in a slightly moistened condition, such as after a small shower of rain, should be avoided, as that often leads to serious soil pulverization and drifting. Tillage should be delayed, therefore, until additional rains have raised the moisture content to a stage at which definite clod formation will take place or, if that is not possible, until medium- and fine-textured soils have thoroughly air dried. Tillage of dry sandy soils should be avoided.

Physical and Chemical Changes in Soils Brought About by Cultivation and Wind Erosion

Analyses showed that fine soil particles are carried across an eroding field much more rapidly than the coarse particles. There is, therefore, a considerable amount of sorting of the soil particles (20), the coarser particles remaining nearer their original location in the field, the finer being blown further away. A shift in wind direction would reverse the process and carry some of the coarse grains towards the original position in the field, but fine dust by that time would be trapped long distances away from the eroding region. This phenomenon acting on the soil throughout the course of many years has caused many soils to become progressively coarser in texture. The separation and removal of fine dust from the original soil can be detected even by casual observation.

The data in Table 33 show that many cultivated soils of the prairies now contain somewhat more sand and less silt and clay than when in the virgin state. Apparently cultivation and consequent accelerated wind erosion during the past 60 years or less have caused these changes, the greatest being in fine sandy soils, the least, if any, in heavy clays. The cultivated soils also have a lower moisture equivalent than the virgin soils, indicating that their water-holding capacity to the depth of tillage has been lowered somewhat.

Cultivated soils also contain appreciably smaller proportions of the non-erosive and semi-erosive water-stable aggregates. The type of farming practised during the agricultural history of the prairies has evidently caused a considerable increase in the erosiveness of many soils. Fortunately, the detrimental effect of the decreased size of the water-stable aggregate is partly counterbalanced, particularly in loam soils, by an increase in the water-stable aggregates smaller

TABLE 33.—PROPERTIES OF VIRGIN AND CULTIVATED SOILS IN THE PRAIRIE PROVINCES*

Soil type	Soil state	Moisture equiv.	Organic matter	Mechanical composition			Water stable aggregates					
				Sand	Silt	Clay	>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25–0·02	<0·02 mm.
		%	%	%	%	%	%	%	%	%	%	%
Manitoba—												
Red River clay	Virgin	46·9	9·16	11·2	15·4	73·4	16·6	15·8	27·8	17·5	16·6	5·6
	Cultivated	45·8	8·25	10·0	14·0	76·0	3·4	13·3	30·4	23·6	21·7	7·6
Oxbow loam	Virgin	24·9	6·75	43·7	35·1	21·2	15·9	9·1	13·8	16·7	40·1	4·4
	Cultivated	23·2	5·76	45·8	34·1	19·6	7·8	5·7	10·0	16·6	47·3	12·5
Almasippi fine sandy loam	Virgin	13·3	4·25	79·6	11·4	9·0	18·4	2·8	4·0	6·0	65·9	2·9
	Cultivated	8·0	2·07	87·6	6·8	5·6	0·2	0·4	0·8	3·7	92·3	2·6
Souris fine sandy loam	Virgin	15·3	4·38	68·8	22·4	8·8	9·7	2·5	3·8	4·9	73·2	5·9
	Cultivated	8·0	2·24	80·2	13·7	6·1	0·6	0·4	0·5	2·2	90·0	6·3
Saskatchewan—												
Regina heavy clay	Virgin	41·7	5·70	14·6	21·4	64·0	2·8	22·4	29·2	18·9	19·6	7·1
	Cultivated	40·3	4·50	14·2	24·0	61·8	1·8	3·2	18·4	23·9	42·5	10·2
Sceptre heavy clay	Virgin	41·1	5·49	12·6	26·9	60·5	4·8	5·6	12·2	18·2	47·2	12·0
	Cultivated	41·1	4·86	11·9	27·4	60·7	0·4	0·7	4·5	16·0	62·3	16·1
Sceptre clay	Virgin	30·7	6·17	17·9	38·6	43·5	18·4	19·2	17·2	12·2	24·2	8·8
	Cultivated	29·5	4·92	18·4	40·5	41·1	4·4	4·8	18·5	16·3	42·6	13·4
Fox Valley silty clay loam	Virgin	26·7	5·80	26·1	47·1	26·8	26·7	19·0	15·7	7·3	21·8	9·5
	Cultivated	25·6	3·32	25·3	50·1	24·6	7·3	5·2	10·1	15·6	46·3	15·5
Haverhill clay loam	Virgin	25·0	5·82	33·9	38·1	28·0	15·8	25·4	16·3	10·2	27·1	5·2
	Cultivated	21·2	4·08	35·9	40·4	23·7	4·2	9·7	17·7	14·9	41·3	12·2
Echo clay loam	Virgin	20·4	4·62	44·7	33·6	21·7	6·4	18·4	22·0	14·1	33·8	5·3
	Cultivated	18·0	3·98	52·9	29·3	17·8	4·1	8·0	13·1	16·0	48·9	9·9
Haverhill loam	Virgin	25·5	5·58	33·1	43·9	23·0	34·6	9·9	10·0	7·9	31·5	6·1
	Cultivated	22·8	4·04	34·7	45·7	19·6	9·5	3·6	8·3	10·5	55·3	12·8
Cypress loam	Virgin	22·4	5·38	34·8	45·2	20·0	49·2	3·3	3·7	7·0	34·8	2·0
	Cultivated	19·4	3·64	39·8	40·1	20·1	30·2	1·7	6·3	10·4	40·9	10·5

* All analyses are based on the top 4 inches of soil.

TABLE 33.—PROPERTIES OF VIRGIN AND CULTIVATED SOILS IN THE PRAIRIE PROVINCES*—*Concluded*

Soil type	Soil state	Moisture equiv.	Organic matter	Mechanical composition			Water stable aggregates					
				Sand	Silt	Clay	>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25–0·02	<0·02 mm.
		%	%	%	%	%	%	%	%	%	%	%
Saskatchewan—Concluded												
Weyburn loam	Virgin	24·8	5·95	44·7	32·7	22·6	38·4	6·6	9·7	10·8	28·1	6·4
	Cultivated	20·7	4·36	48·7	31·2	20·1	2·2	4·6	9·6	11·3	53·9	18·4
Oxbow loam	Virgin	25·8	9·06	41·5	34·4	24·1	55·9	6·2	7·1	6·2	19·4	5·2
	Cultivated	23·9	6·03	46·5	30·0	23·5	6·2	4·3	8·4	12·3	53·9	15·8
Hatton fine sandy loam	Virgin	17·1	3·29	60·8	28·1	11·1	26·9	5·1	4·8	4·3	53·1	5·8
	Cultivated	14·3	3·35	66·6	23·5	9·9	5·6	2·2	4·4	7·0	73·7	7·1
Asquith fine sandy loam	Virgin	18·4	5·12	65·2	23·5	11·3	17·2	8·7	14·2	5·3	49·7	4·9
	Cultivated	11·8	3·11	71·7	19·1	9·2	1·5	2·8	4·8	12·2	71·8	6·9
Alberta—												
Heavy clay (dark brown)	Virgin	44·1	7·20	10·2	29·0	60·8	30·8	9·5	15·6	16·0	25·0	3·1
	Cultivated	44·6	5·58	9·6	32·8	57·6	0·7	2·9	16·3	31·2	41·5	7·4
Clay loam (dark brown)	Virgin	20·1	3·22	45·0	26·6	28·4	81·9	2·2	1·7	2·3	11·9	0·0
	Cultivated	19·5	1·78	49·6	24·0	26·4	2·0	2·5	7·5	12·2	70·8	5·0
Clay loam (brown)	Virgin	22·1	4·81	31·6	40·6	27·8	47·0	24·4	10·9	11·8	4·9	1·0
	Cultivated	20·7	2·90	35·2	41·6	24·2	0·1	3·1	9·5	13·2	60·1	14·0
Silt loam (dark brown)	Virgin	22·2	4·65	31·4	47·2	21·4	49·8	6·0	7·8	5·6	28·0	2·8
	Cultivated	21·5	3·78	35·0	47·6	17·4	0·5	1·0	4·6	6·9	72·0	15·0
Loam (dark brown)	Virgin	20·1	2·33	47·0	31·6	21·4	54·6	7·4	7·5	6·8	23·7	0·0
	Cultivated	19·3	1·78	46·0	31·4	22·6	2·5	2·6	8·4	10·5	69·0	7·0
Loam (brown)	Virgin	19·8	3·59	37·0	40·4	22·6	38·7	4·0	11·2	11·7	29·2	5·2
	Cultivated	18·1	2·90	36·0	45·6	18·4	0·7	1·3	4·2	11·4	67·0	15·4
Fine sandy loam (dark brown).	Virgin	18·8	4·41	61·0	25·6	13·4	50·4	4·5	11·0	15·1	17·5	1·5
	Cultivated	13·4	4·19	70·0	18·4	11·6	7·4	2·3	12·0	29·2	45·0	4·1
Fine sandy loam (brown)	Virgin	13·7	2·46	60·8	21·6	17·6	31·8	1·9	3·6	5·1	55·0	2·6
	Cultivated	9·7	1·50	73·0	17·0	10·0	1·0	0·8	1·5	3·6	89·5	3·6

* All analyses are based on the top 4 inches of soil.

than 0·02 mm. in diameter. If it were not for the presence of these fine cementing particles the cultivated soils would be appreciably more susceptible to wind erosion than they are at the present time. Unfortunately this property makes them highly susceptible to water erosion (34), which is becoming more prevalent on the prairies.

The organic matter and nitrogen were found to be lower in the cultivated than in the virgin soils, the greatest difference being in sandy soils, the least in heavy clays. It should be pointed out, however, that the changes in texture of dryland soils are even more serious than the losses in plant nutrients—for depleted fertility can be restored by proper cropping and manurial practices, where the loss of valuable structure-forming and moisture-retaining clay fractions can never be replaced.

The data in Table 34 give some information of the relative effect of perennial grasses on soil structure. It may be observed that returning the land to grass for a period of years produces soil structure approaching that under virgin conditions and this is the only known way of achieving this effect.

TABLE 34.—THE EFFECT OF PERENNIAL GRASS CROPS ON WATER-STABLE SOIL STRUCTURE

Soil type	Soil state	Water-stable aggregates					
		>2·0 mm.	2·0–0·83	0·83–0·42	0·42–0·25	0·25–0·02	<0·02 mm.
		per cent	per cent	per cent	per cent	per cent	per cent
Sceptre heavy clay	Crested wheat grass 7 yrs	2·8	1·6	8·4	24·1	52·9	12·2
	Cultivated	0·6	0·7	2·2	10·8	65·0	20·7
Regina heavy clay	Brome 9 yrs	6·4	8·6	18·8	23·1	31·3	11·8
	Cultivated	1·4	2·9	10·0	26·5	42·9	16·3
Sceptre clay	Crested wheat grass 5 yrs	25·9	4·1	11·9	8·7	39·6	9·8
	Cultivated	5·0	4·0	15·0	16·8	45·5	13·7
Fox Valley silty clay loam	Crested wheat and alfalfa 17 yrs	33·1	7·0	14·8	10·3	24·4	10·4
	Cultivated	6·3	6·1	14·5	13·2	43·9	16·0
Haverhill loam	Brome 10 yrs	16·9	3·0	10·6	14·3	48·5	6·7
	Cultivated	7·0	3·1	10·7	15·8	53·9	9·5
Weyburn loam	Brome 6 yrs	22·6	5·5	11·4	11·9	35·1	13·5
	Cultivated	2·2	4·6	9·6	11·3	53·9	18·4
Oxbow loam	Brome 5 yrs	34·4	9·7	13·4	11·9	26·3	4·3
	Cultivated	4·7	6·9	13·1	15·3	48·8	11·2

The low degree of erosiveness of newly broken land is dependent on the increased size and stability of the water-stable aggregates as well as the mechanical effect of the roots and crowns of the plants. Fields that had been in grass for only 4 years showed an increase in aggregation and moisture-holding capacity (33) but a longer period is essential for an appreciable effect. The resistance to erosion of fields that have been broken after being in grass only 3 or 4 years is due almost entirely to the binding action of the roots. As soon as the roots are decomposed the fields drift as readily as before seeding down. Grass cannot be used effectively in a short term rotation in the semi-arid region for improving the physical and chemical condition of the soil.

WEED CONTROL

When weeds pollute the land it is practically impossible to get rid of them completely, because viable seeds may remain in the soil for many years and only a small percentage germinate in any one year. Some weed seeds do not exhibit such marked dormancy and for this reason alone require entirely different cultural methods for their extermination.

Experiments were undertaken at this Laboratory in 1937 to determine the nature and extent of dormancy of seeds of different weeds in order to find methods of cultivation that would facilitate their eradication. The studies included fifty-eight of the most common weeds. Although it was possible to classify the weeds into certain broad categories with respect to behaviour of seeds in cultivated soil, there were nevertheless great differences between the individual species. A brief description of the broad classes is given in this report but a more detailed description of each species is given in another publication (21).

Longevity and Periodicity of Germination of Weeds

The primary object of this study was to find, if possible, the length of time required to completely rid the land of weeds, provided no weeds were allowed to produce seed and infestation from outside sources was prevented. The study was carried further to determine the relative value of each year of clean crop or summerfallow in reducing the weed-seed population of the soil.

The data in Table 35 comprise the final results of a third experiment on the relative longevity of weed seeds in cultivated soil. Lots of one thousand seeds of the various species were planted in bottomless trays containing clay, loam and sandy loam soils. No seeds were planted deeper than 3 inches and all subsequent cultural operations were to a 3-inch depth only. The soil in the trays was seeded to grain every second year and cultivated occasionally during the fallow year. As there was little, if any, difference in the number of seeds germinating in the different soils, the final results, as reported in Table 35, are an average of the three soils.

TABLE 35.—LONGEVITY OF WEED SEEDS IN CULTIVATED SOIL

(Seeds planted in surface 3″ of soil, Nov. 1940)

Weed	Number of seeds sown	Number of viable seeds	Numbers emerged						
			1941 fallow	1942 crop	1943 fallow	1944 crop	1945 fallow	1946 crop	1947 fallow
Downy brome	1,000	900	177	1	0	0	0	0	0
Couch grass	1,000	390	391	0	0	0	0	0	0
Darnel	1,000	620	408	17	0	0	0	0	0
Wild barley	1,000	510	473	3	11	0	0	1	0
Wild oats	1,000	400	225	46	11	0	0	0	0
Green foxtail	1,000	760	520	1	3	0	0	0	0
Willow-leaved dock	1,000	120	34	0	0	0	0	0	0
Knotweed	1,000	310	203	22	4	3	1	0	0
Wild buckwheat	1,000	500	411	10	0	0	0	0	0
Lamb's quarters	1,000	550	16	6	20	21	7	3	6
Spearleaf goosefoot	1,000	760	37	1	8	16	16	15	1
Kochia	1,000	720	123	0	0	0	0	2	0
Bugseed	1,000	430	119	16	44	9	2	3	2
Garden atriplex	1,000	870	418	11	13	2	1	0	0
Hastate atriplex	1,000	490	331	20	13	14	1	0	2
Russian pigweed	1,000	590	140	37	22	25	5	2	2
Russian thistle	1,000	500	268	0	1	0	0	0	0
Red-root pigweed	1,000	710	190	1	9	19	5	5	0
Prostrate amaranth	1,000	370	233	24	20	37	15	13	3
Tumbleweed	1,000	340	143	2	12	28	4	0	0
Purslane	1,000	440	36	2	3	9	4	0	0
Corn spurry	1,000	1,000	80	10	23	13	2	8	0
Purple cockle	500	475	197	0	0	0	0	0	0

TABLE 35.—LONGEVITY OF WEED SEEDS IN CULTIVATED SOIL—*Concluded*

(Seeds planted in surface 3″ of soil, Nov. 1940)

Weed	Number of seeds sown	Number of viable seeds	Numbers emerged						
			1941 fallow	1942 crop	1943 fallow	1944 crop	1945 fallow	1946 crop	1947 fallow
Night flowering catchfly	1,000	1,000	227	7	105	24	7	7	0
Bladder campion	1,000	950	175	4	18	15	5	5	0
Cow cockle	1,000	920	476	5	0	0	0	0	0
Perfoliate peppergrass	1,000	620	60	0	17	8	14	6	11
Peppergrass	1,000	1,000	85	21	14	22	1	10	2
Stinkweed	1,000	970	251	66	56	5	0	0	0
Shepherd's purse	1,000	200	20	8	15	10	0	0	0
False flax	1,000	970	397	0	0	0	0	0	0
Round seeded false flax	1,000	1,000	609	0	0	0	0	0	0
Small seeded false flax	1,000	880	456	0	0	0	0	0	0
Tumbling mustard	1,000	960	57	0	5	1	0	1	0
Flixweed	1,000	600	49	12	22	13	6	2	5
Hare's ear mustard	1,000	610	329	1	0	0	0	0	0
Wormseed mustard	1,000	350	54	4	21	17	3	10	1
Wild mustard	1,000	700	238	12	44	9	3	6	0
Dog mustard	1,000	700	129	1	10	1	1	2	0
Indian mustard	1,000	990	184	0	2	1	0	0	0
Indian pink	700	586	298	71	1	8	1	2	1
Black medick	1,000	460	14	134	18	33	5	5	7
Evening primrose	1,000	430	63	12	6	25	1	10	9
Milkweed	1,000	230	28	3	0	0	0	0	0
Wild morning glory	1,000	570	13	1	2	4	9	6	5
Blue bur	1,000	820	135	1	1	1	0	1	0
Plantain	1,000	380	48	1	0	13	3	3	12
False ragweed	1,000	280	24	8	2	6	0	1	1
Cocklebur	1,000	280	142	58	2	4	1	0	1
Gumweed	1,000	530	16	26	10	15	1	14	6
Wild sunflower	1,000	340	160	37	7	9	1	4	1
Canada thistle	1,000	40	19	1	0	0	0	0	0
Yellow goat's beard	250	230	48	0	0	0	0	0	0
Dandelion	1,000	230	33	5	2	4	0	1	0
Lobed prickly lettuce	1,000	130	58	3	3	3	1	0	0
Dentate prickly lettuce	1,000	160	57	7	0	0	0	0	0
Perennial sow thistle	1,000	240	15	0	1	2	0	0	0

The number of viable seeds was determined by a germination test of a second lot of seeds from the same samples. The seeds were placed in flower pot saucers in a layer of fine sand 1 cm. deep and subjected to favourable germinating conditions at periodic intervals. The seeds were all subjected to freezing temperature at least once during the germination test which extended from November, 1940, to November, 1945. Near the end of this period, no seeds were germinating except night-flowering catchfly, black medick, wild morning glory and plantain. The remaining seeds of these species were treated with sulphuric acid, which broke the dormancy period of the viable seeds.

The data indicate that while seeds of some species lie dormant in cultivated soil for only a short time, many species contain a certain proportion of seeds that remain dormant for many years. On the basis of information obtained from this and previous experiments (21), the weeds can be listed in approximate order from the shortest to the longest average period of seed dormancy as follows:

None to very short (maximum period of dormancy not exceeding 1 year):

1. *Agrostemma githago* .... Purple cockle, corn cockle
2. *Camelina microcarpa* .... Small seeded false flax
3. *Camelina sativa* .... False flax
4. *Camelina dentata* .... Round seeded or flat seeded false flax
5. *Kochia trichophylla* .... Kochia
6. *Tragopogon dubius* .... Yellow-goat's beard

Short to intermediate (maximum length of dormancy from 1 to 3 years):

7.	*Conringia orientalis*	Hare's ear mustard
8.	*Brassica juncea*	Indian mustard
9.	*Salsola Pestifer*	Russian thistle
10.	*Vaccaria vulgaris*	Cow cockle
11.	*Setaria viridis*	Green foxtail
12.	*Rumex mexicanus*	Willow-leaved dock
13.	*Cirsium arvense*	Canada thistle
14.	*Lolium rigidum*	Darnel
15.	*Asclepias speciosa*	Milkweed
16.	*Bromus tectorum*	Downy brome
17.	*Bilderdykia Convolvulus*	Wild buckwheat
18.	*Hordeum jubatum*	Wild barley

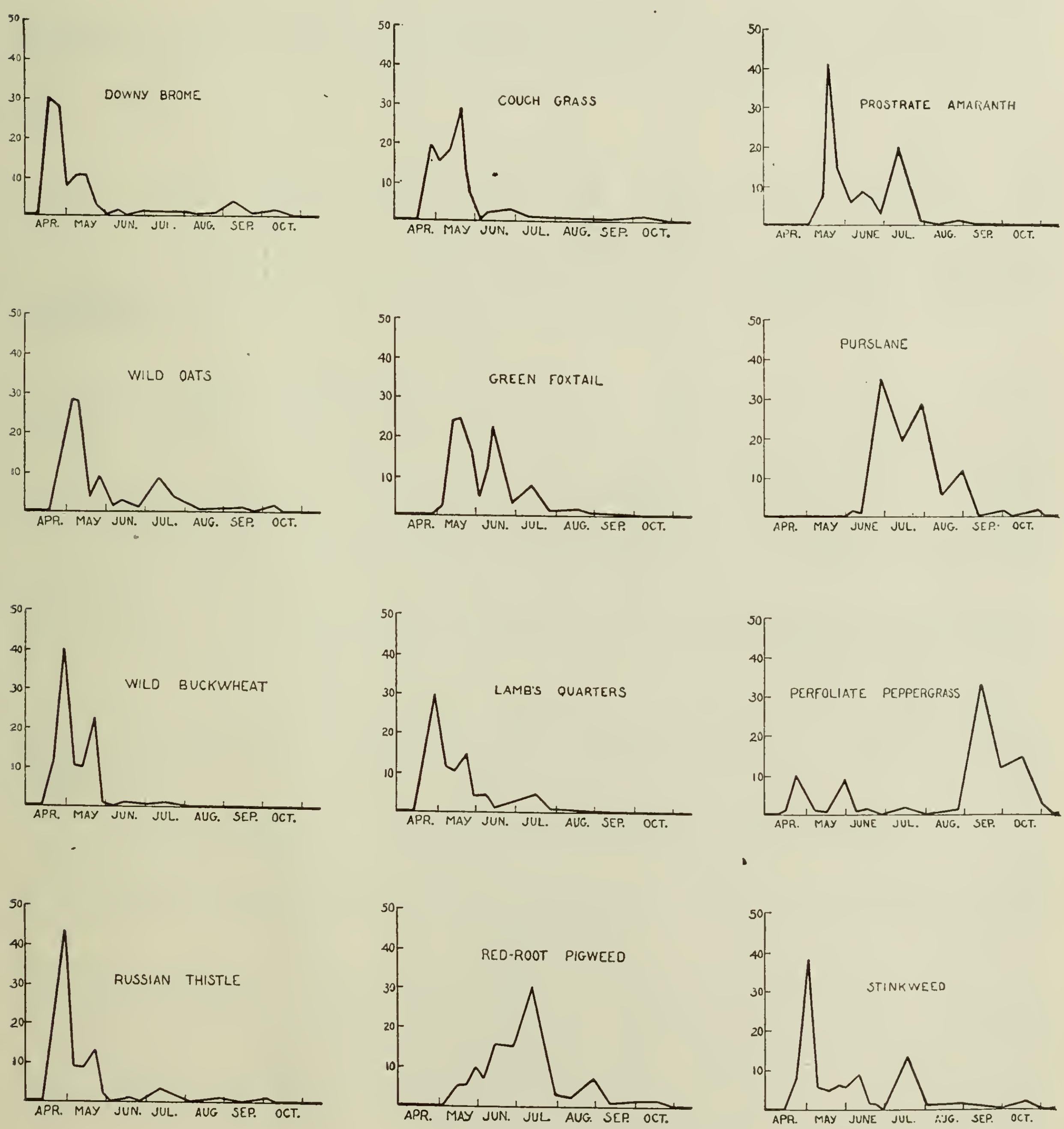
Long to very long (maximum length of dormancy exceeding 3 years):

19.	*Agropyron repens*	Couch grass, quack grass
20.	*Lappula echinata*	Blue bur
21.	*Lactuca virosa*	Dentate prickly lettuce
22.	*Avena fatua*	Wild oats
23.	*Atriplex hortensis*	Garden atriplex
24.	*Polygonum neglectum*	Knotweed
25.	*Atriplex hastata*	Hastata atriplex
26.	*Erucastrum gallicum*	Dog mustard
27.	*Peritoma serrulatum*	Indian pink
28.	*Taraxacum officinale*	Dandelion
29.	*Xanthium echinatum*	Cocklebur
30.	*Sonchus arvensis*	Perennial sow thistle
31.	*Solanum triflorum*	Wild mustard
32.	*Helianthus aridus*	Wild sunflower
33.	*Thlaspi arvense*	Stinkweed
34.	*Lactuca Scariola*	Lobed prickly lettuce
35.	*Silene vulgaris*	Bladder campion
36.	*Sinapis arvensis*	Wild mustard
37.	*Sisymbrium altissimum*	Tumbling mustard
38.	*Axyris amaranthoides*	Russian pigweed
39.	*Spergula arvensis*	Corn spurry
40.	*Oenothera strigosa*	Evening primrose
41.	*Silene noctiflora*	Night flowering catchfly
42.	*Cheirinia cheiranthoides*	Wormseed mustard
43.	*Amaranthus graecizans*	Tumbleweed
44.	*Amaranthus retroflexus*	Red-root pigweed
45.	*Amaranthus blithoides*	Prostrate amaranth, prostrate pigweed
46.	*Corispermum marginale*	Bugseed
47.	*Cyclachaena xanthifolia*	False ragweed
48.	*Sophia multifida*	Flixweed
49.	*Chenopodium album*	Lamb's quarters
50.	*Plantago major*	Broad-leaved plantain
51.	*Lepidium densiflorum*	Peppergrass
52.	*Lepidium perfoliatum*	Perfoliate peppergrass
53.	*Capsella Bursa-pastoris*	Shepherd's purse
54.	*Grindelia perennis*	Gumweed
55.	*Portulaca oleracea*	Purslane
56.	*Medicago lupulina*	Black medick
57.	*Monolepis Nuttalliana*	Spear-leaf goosefoot
58.	*Convolvulus americanus*	Wild morning glory

Six of the species, out of a total of fifty-eight, had seeds whose life span in cultivated soil did not exceed one year and eighteen had seeds that remained dormant in cultivated soil for periods not exceeding three years, except that a few of these had one or two seeds out of several thousands live past this period. None of these weeds with the exception of Russian thistle and Canada thistle is particularly serious, evidently because of their short longevity in cultivated soil.

A number of species, about 22 to 28, depending on where the borderline cases are to be included, contained relatively few seeds that remained dormant at shallow depths in cultivated soil beyond a period of three years, and it is evident that these species could be controlled by suitable tillage practices. Approximately thirty of the species are shown to possess a particularly long period of dormancy in cultivated soil and constitute a very serious agricultural problem.

On the whole, there was little, if any, difference in the average period of dormancy of seeds mixed with clay, loam, or sandy loam soil.



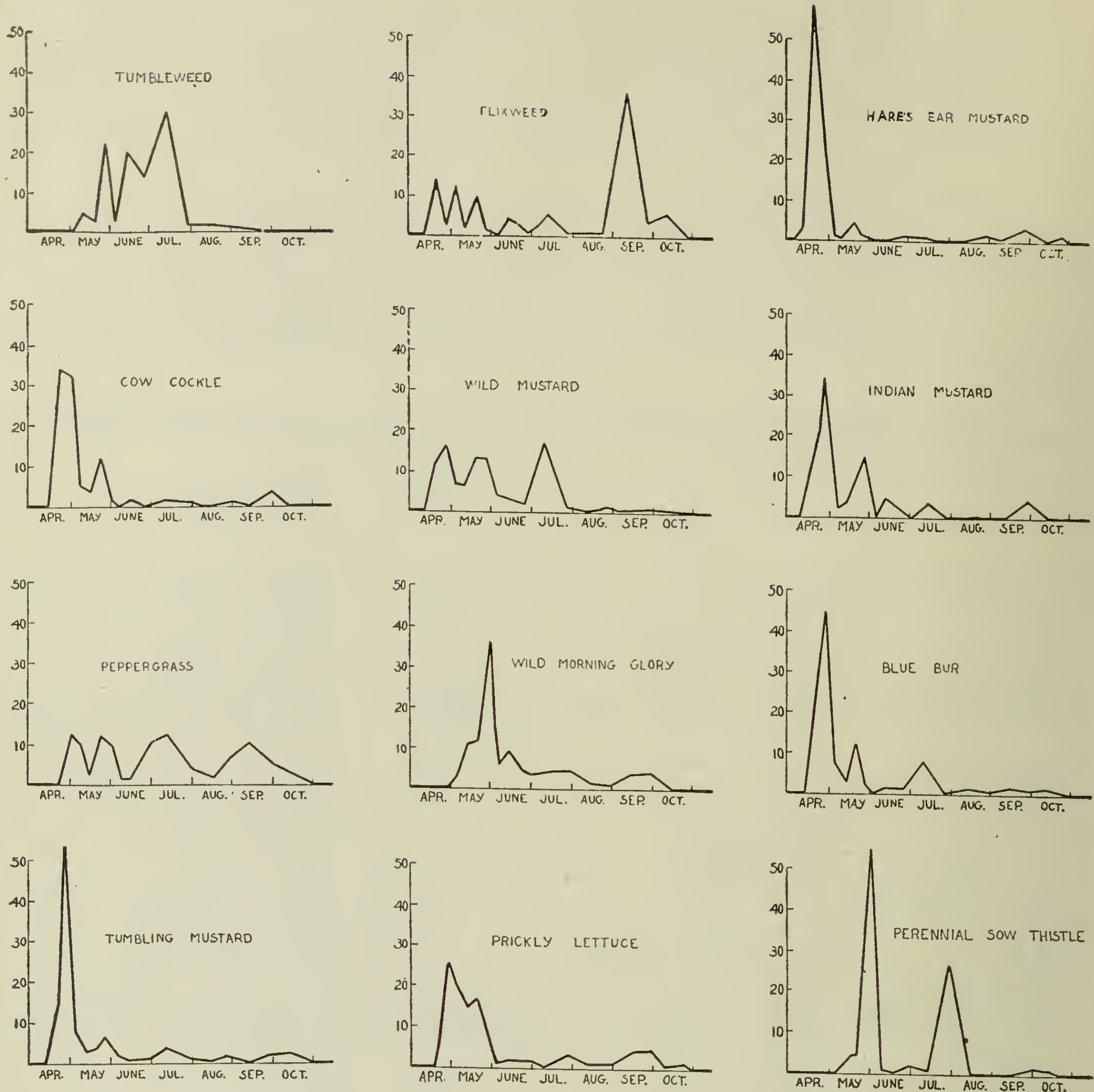


Fig. 22.—Periodicity of germination of some common weeds, expressed in per cent of total yearly germination.

Most of the weeds showed a definite tendency to germinate only during certain periods of the year (Fig. 22). The periodicity of germination in the field was bout the same on clay, loam, and sandy loam soils, but varied markedly with each species and was not entirely dependent on the variation in the moisture content of the soil. The periodicity of germination throughout the year after ripening was found to be the same as that for seeds which have lain in cultivated soil for more than one year. No germination occurred between November 15 and March 31, for the land was frozen during most of this period.

There was not a single period of the growing season when seeds of some species did not show a substantial emergence in the field. For the majority of the species studied, however, the peak of germination occurred within a relatively short period of about three weeks commencing about April 23, followed by general tapering off in germination until midsummer or fall. In some species, particularly the winter annuals, the second peak, though, in most cases not so pronounced as the first, occurred in the fall.

Although the majority of the species had a peak germination early in the spring, some germinated in substantial numbers late in the spring, others only during the summer months and still others only in the fall of the year. There were some species, on the other hand, whose germination was more or less haphazard and showed no marked or regular periodicity, but the number of such species was relatively small. For some, the period during which substantial numbers or the majority of the seeds germinated, was very short, but for others substantial numbers of seeds continued to germinate throughout the whole or most of the growing season. For the great majority, the period or periods of high germination were apparently determined by the inherent behaviour of the seeds so that any variation in the weather had little, if any, influence on the actual behaviour of the dormant seeds.

The species investigated can be classed into several broad classes with respect to periodicity of germination, as follows:

Species germinating in greatest numbers early in the spring (April 23 to May 15): Purple cockle, false flax, small seeded false flax, large seeded false flax, kochia, goat's beard, hare's ear mustard, Indian mustard, Russian thistle, darnel, downy brome, wild buckwheat, wild barley, couch grass, dentate prickly lettuce, blue bur, garden atriplex, Indian pink, cocklebur, stinkweed, wild sunflower, lobed prickly lettuce, tumbling mustard, false ragweed, Russian pigweed, lamb's quarters, plantain.

Species germinating in greatest numbers usually in mid-spring (May 7 to May 31): Green foxtail, willow-leaved dock, Canada thistle, milkweed, wild tomato, perennial sow thistle, bugseed, evening primrose, wild morning glory.

Species with peak germination between late spring and midsummer (May 31 to August 31): Prostrate amaranth, red-root pigweed, tumbleweed, shepherd's purse, purslane.

Species germinating most readily in the autumn (September–October): Flixweed, perfoliate peppergrass.

Species not showing any regular or marked periodicity: Dog mustard, dandelion, bladder campion, wild mustard, corn spurry, night-flowering catchfly, gumweed, black medick, wormseed mustard, spear-leaf goosefoot, peppergrass.

The data in Table 35 show that for most species not over 50 per cent of the weed seeds emerged in the field and in many cases not over 10 per cent. The low emergence of seedlings in the field was found to be due to two main factors, the low viability of seeds of many species and the high mortality of seedlings before or immediately after emergence. These seemingly serious characteristics, as far as survival of the species is concerned, are no doubt more than compensated by the high degree of dormancy and delayed germination of some of the seeds. These remaining seeds apparently ensure sufficient plants to keep the land infested.

The Influence of Tillage on the Germination of Weed Seeds

The emergence of weeds and the number of viable seeds surviving various soil treatments under field conditions varied markedly with different species (22). Of the five species under study, Russian thistle showed the least tendency to natural dormancy, resulting in marked reductions of viable seeds in the soil irrespective of the depth of tillage, Table 36. The four other species showed that their seeds tend to prolonged dormancy and therefore to greater variation in response to different cultural treatments, Fig. 23. Many Russian thistle seeds emerged readily from shallow depths, but others rotted, in some cases within a year, when they were buried too deeply to emerge. In a few cases a small percentage of seeds survived burial in the soil for more than one year.

TABLE 36.—THE INFLUENCE OF CULTURAL TREATMENTS ON THE GERMINATION AND GROWTH OF RUSSIAN THISTLE ON LOAM SOILS

Weed	Tillage treat-ment*	Seasonal emergence 6-year average		Viable seeds remaining in soil after exposure during†					
		To June 30	After June 30	1937	1938-39	1940	1941	1942	Average
		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Russian thistle...........	1	42·6	1·3	0·3	0·0	0·0	0·0	0·1	0·1
	2	22·2	0·8	0·1	0·0	0·1	0·1	0·2	0·1
	3	21·9	0·6	0·1	0·0	0·1	0·2	0·2	0·1
	4	20·9	0·5	0·1	0·0	0·2	0·1	0·1	0·1
	5	25·3	0·1	0·1	0·0	0·3	0·2	0·3	0·2
	6	11·1	0·4	....	0·0	1·3	0·2	0·6	0·5
	7	11·7	0·4	....	0·0	0·7	0·2	0·1	0·2

* As indicated under Fig. 22.
† Determined by repeated subjection to germination in the laboratory until no more seedlings emerged.

The highest emergence of all small-seeded species was from seeds placed on the surface of the ground. The deeper the seeds were buried, the lower was the emergence. The greatest depth from which any of the small-seeded species germinated was three inches. This suggests that shallow tillage is more effective in reducing the weed seed population of the soil than deep tillage. While the above statement is true for most weed species, it does not apply to Russian thistle and a few other weeds whose seeds either germinate or soon lose their viability after they are buried in the soil. It seems that it should be a relatively easy matter to eradicate Russian thistle, provided seed production on cultivated land and contamination from uncultivated waste areas are prevented. As seeds of Russian thistle do not readily shatter, surface tillage does not bring them all in contact with the soil where they may germinate and subsequently be destroyed by tillage. Ploughing to bury all seeds, or burning, is effective in destroying them but either practice is often conducive to soil drifting.

Russian thistle is also difficult to keep in check on account of its rapid growth in stubble in the fall after the grain is harvested. Tillage of stubble soon after the grain crop is removed will keep the infestation down, but this practice may cause serious soil drifting, unless the stubble is buried as little as possible. The blade weeders appear to be suitable for this purpose.

Apart from the results obtained with Russian thistle, periodical tillage of summerfallow containing weed seeds all the way down to the depth of tillage increased the numbers of weeds emerged, but the increase was marked only after June 30. This seems to be due more to the fact that tillage brought buried seeds to the surface after those originally on or near the surface had germinated, rather than to some stimulating effect of cultivation on germination. The number of viable seeds surviving fallow, cultivated periodically throughout one season was, on the whole, substantially lower than the number surviving in an undisturbed soil which originally contained weed seeds to the depth of tillage.

On the average, packing after each tillage operation appeared to have little, if any, effect on the germination and emergence of weeds. In one case, surface packing of moist loam soil after a 1·71-inch rain caused a marked

increase in the emergence of stinkweed, tumbleweed, prostrate amaranth, and redroot pigweed. It is evident that packing dry or only slightly moist soil is ineffective in increasing the germination of weed seeds but packing moist soil may occasionally stimulate germination.

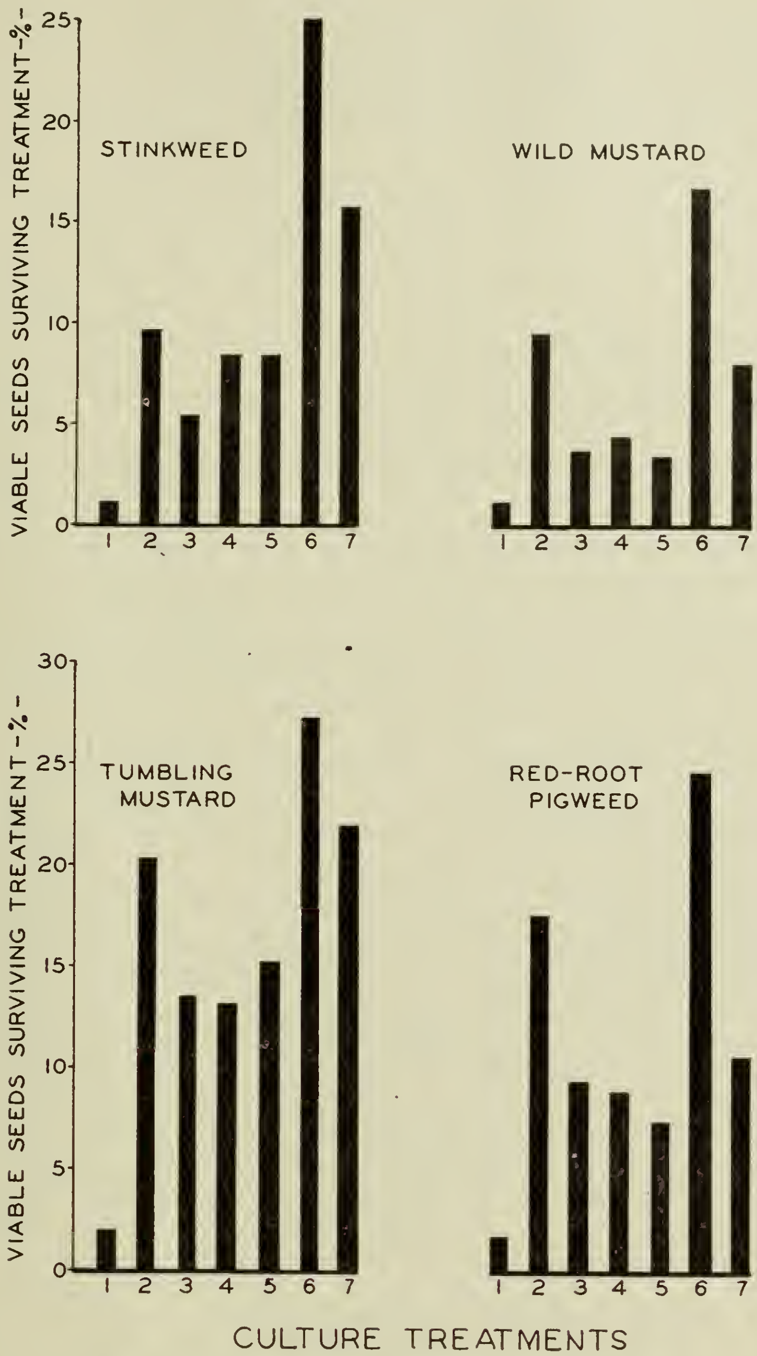


Fig. 23.—Average percentage of viable seeds surviving one season of tillage treatments on loam soil:

Treatment 1.—Seeds scattered on the surface, no tillage.
Treatment 2.—Seeds mixed in 2·5-inch layer of soil, no tillage.
Treatment 3.—Seeds mixed in 2·5-inch layer of soil, cultivated 4 times to 2·5-inch depth.
Treatment 4.—Seeds mixed in 2·5-inch layer of soil, cultivated 4 times to 2·5-inch depth and packed.
Treatment 5.—Seeds mixed in 2·5-inch layer of soil, cultivated 4 times to 2·5-inch depth and watered to keep continually moist.
Treatment 6.—Seeds mixed in 6-inch layer of soil, no tillage.
Treatment 7.—Seeds mixed in 6-inch layer of soil, cultivated to 6-inch depth June 1, cultivated 3 times to 2·5-inch depth.

Contrary to what was expected there was no appreciable difference in the germination of weed seeds in soil kept continually moist as compared with soil receiving no more than the natural precipitation. The longevity of weed seeds in periodically cultivated dryland soils is apparently due to their natural dormancy and not to the limited supply of soil moisture. At one time or another there is sufficient rainfall during the growth season to cause the germination of all seeds whose natural dormancy has been broken. An increase in precipitation over and above that required to germinate the weed seeds does not seem to affect the condition of the naturally dormant seeds.

REFERENCES

1. Bagnold, R. A. The movement of desert sand. Proc. Roy. Soc. of London, Series A. 157: 594-620, 1936.
2. Bagnold, R. A. The measurement of sand storms. Proc. Roy. Soc. of London, Series A. 167: 282-291, 1938.
3. Barnes, S. Soil moisture and crop production under dry land conditions in Western Canada. Dominion of Canada, Dept. of Agriculture, Publication 595, 1938.
4. Bradley, W. B., H. F. Eppsen, and O. A. Beath. Livestock poisining by oat hay and other plants containing nitrates. Wym. Agr. Exp. Stn., Bul. 241, 1940.
5. Callendar, H. L. and C. H. McLeod. Observations in soil temperature with electrical resistance thermometers. Trans. Roy. Soc. Can., Vol. 3: 31-49, 1897.
6. Chepil, W. S. and R. A. Milne. Comparative study of soil drifting in the field and in a wind tunnel. Sci. Agr. 19: 249-257, 1939.
7. Chepil, W. S. The relation of wind erosion to some physical soil characteristics. Thesis. Univ. of Minn., 1940.
8. Chepil, W. S. Relation of wind erosion to the dry aggregate structure of a soil. Sci. Agr. 21: 488-507, 1941.
9. Chepil, W. S. and R. A. Milne. Wind erosion of soils in relation to size and nature of the exposed area. Sci. Agr. 21: 479-487, 1941.
10. Chepil, W. S. and R. A. Milne. Wind erosion of soil in relation to roughness of surface. Soil Sci. 52: 417-433, 1941.
11. Chepil, W. S. Measurement of wind erosiveness of soil by dry sieving procedure, Sci. Agr. 23: 154-160, 1942.
12. Chepil, W. S. Relation of wind erosion to the water-stable and dry clod structure of soil. Soil Sci. 55: 275-287, 1943.
13. Chepil, W. S. and F. Bisal. . A rotary sieve method for determining the size distribution of soil clods. Soil Sci. 56: 95-100, 1943.
14. Chepil, W. S. Utilization of crop residue for wind erosion control. Sci. Agr. 24: 307-319, 1944.
15. Chepil, W. S. Dynamics of wind erosion: I. Nature of movement of soil by wind. Soil Sci. 60:305-320, 1945.
16. Chepil, W. S. Dynamics of wind erosion: II. Intitiation of soil movement. Soil Sci. 60: 397-411, 1945.
17. Chepil, W. S. Dynamics of wind erosion: III. The transport capacity of the wind. Soil Sci. 60: 475-480, 1945.
18. Chepil, W. S. Dynamics of wind erosion: IV. The translocating and abrasive action of the wind. Soil Sci. 61: 167-177, 1946.
19. Chepil, W. S. Dynamics of wind erosion: V. Cumulative intensity of soil drifting across eroding fields. Soil Sci. 61: 257-263, 1946.
20. Chepil, W. S. Dynamics of wind erosion: VI. Sorting of soil material by the wind. Soil Sci. 61: 331-340, 1946.
21. Chepil, W. S. Germination of weed seeds: I. Longevity, periodicity of germination, and vitality of seeds in cultivated soil. Sci. Agr. 26: 307-346, 1946.
22. Chepil, W. S. Germination of weed seeds: II. The influence of tillage treatments on germination. Sci. Agr. 26: 347-357, 1946.
23. Cole, L. J. and O. R. Mathews. Use of water by spring wheat in the great plains. U.S.D.A., Bul. 1004, 1923.
24. Davidson, W. B., J. L. Doughty, and J. L. Bolton. Nitrate poisoning of livestock. Can. Jour. of Comp. Med. 51: 303-313, 1941.
25. Doughty, J. L. and A. E. Stalwick. The effect of alkali salts on plant growth. Sci. Agr. 20: 272-276, 1940.
26. Doughty, J. L. The advantages of a soil paste for pH determinations. Sci. Agr. 22: 136-138, 1941.
27. Doughty, J. L. and F. G. Warder. The accumulation of nitrate in oat straw. Sci. Agr. 23: 233-236, 1942.
28. Doughty, J. L. The maintenance of organic matter in the brown soils. Sci. Agr. 28: 88-95, 1948.
29. Fisher, E. A. Some factors affecting the evaporation of water from soil. Jour. Agr. Sci. 13: 121-143, 1923.
30. Hopkins, J. W. Agricultural Meteorology: A statistical study of conservation of precipitation by summerfallowed soil tanks at Swift Current, Sask. Can. Jour. Res. C. 18: 388-400, 1940.

REFERENCES—Concluded

31. Keen, B. A. The physical properties of the soil. Longman Green and Company, p. 308, 1931.
32. Keen, B. A. The evaporation of water from soil. Jour. Agr. Sci. 6: 456-475, 1914.
33. Lehane, J. J., and W. J. Staple. The effect of crested wheat grass on some physical and chemical characteristics of the soil. Sci. Agr. 23: 509-517, 1943.
34. Middleton, H. E. Properties of soil which influence soil erosion. U.S.D.A. Tech. Bul. 178, 1930.
35. Moore, R. E. Water conduction from a shallow water table. Hilgardia 12: 383-426, 1939.
36. Newton, J. D., F. A. Wyatt, and A. L. Brown. Effect of cultivation and cropping on the chemical composition of some Western Canada prairie soils. III. Sci. Agr. 25: 718-737, 1945.
37. Parkinson, G. R. Dust storms over the Great Plains, Bul. Amer. Met. Soc. 17: 127-135, 1936.
38. Penman, H. L. Laboratory experiments on evaporation from fallow soil. Jour. Agr. Sci. 31: 454-465, 1941.
39. Report of Investigations, Soil Research Laboratory, Swift Current, Saskatchewan, 1943. Dominion of Canada, Department of Agriculture, Ottawa.
40. Snedecor, G. W. Statistical Methods 1938. Collegiate Press Inc.
41. Staple, W. J. and J. J. Lehane. The use of the wilting coefficient in soil moisture studies in southwestern Saskatchewan. Sci. Agr. 21: 440-447, 1941.
42. Staple, W. J. and J. J. Lehane. The estimation of soil moisture conservation from meteorological data. Soil Sci. 58: 177-193, 1944.
43. Veihmeyer, F. J. and A. H. Hendrickson. The moisture equivalent as a measure of the field capacity of soils. Soil Sci. 32: 181-193, 1931.

EXPERIMENTAL FARMS SERVICE

Director, E. S. Archibald, B.A., B.S.A., LL.D., D.Sc.
Associate Director, E. S. Hopkins, B.S.A., M.S., Ph.D.

Dominion Field Husbandman.......................... P. O. Ripley, B.S.A., M.S., Ph.D.
Dominion Horticulturist.......................... M. B. Davis, B.S.A., M.Sc.
Dominion Cerealist.......................... C. H. Goulden, B.S.A., M.S.A., Ph.D.
Dominion Animal Husbandman.......................... G. W. Muir, B.S.A.
Dominion Agrostologist.......................... T. M. Stevenson, B.S.A., M.Sc., Ph.D.
Chief, Poultry Division.......................... H. S. Gutteridge, B.S.A., M.Sc.
Chief, Tobacco Division.......................... N. A. MacRae, B.A., M.Sc., Ph.D.
Dominion Apiarist.......................... C. B. Gooderham, B.S.A.
Chief Supervisor of Illustration Stations.......................... J. C. Moynan, B.S.A.
Economic Fibre Specialist.......................... R. J. Hutchinson

PRINCE EDWARD ISLAND

Superintendent, Experimental Station, Charlottetown, R. C. Parent, B.S.A., M.S.
Superintendent, Experimental Fox Ranch, Summerside, C. K. Gunn, B.Sc., Ph.D.

NOVA SCOTIA

Superintendent, Experimental Farm, Nappan, W. W. Baird, B.S.A.
Superintendent, Experimental Station, Kentville, A. Kelsall, B.S.A.

NEW BRUNSWICK

Superintendent, Experimental Station, Fredericton, S. A. Hilton, B.S.A., M.Sc.

QUEBEC

Superintendent, Experimental Station, Lennoxville, J. A. Ste. Marie, B.S.A.
Superintendent, Experimental Station, Ste. Anne de la Pocatiere, J. R. Pelletier, B.A., B.S.A., M.Sc.
Superintendent, Experimental Station, L'Assomption, R. Bordeleau, B.S.A.
Superintendent, Experimental Station, Normandin, A. Belzile, B.S.A.
Officer-in-Charge, Experimental Substation, Ste. Clothilde, F. S. Browne, B.S.A.

ONTARIO

Central Experimental Farm, Ottawa.
Superintendent, Experimental Station, Kapuskasing, E. T. Goring, B.S.A.
Superintendent, Experimental Station, Harrow, H. F. Murwin, B.S.A.
Officer-in-Charge, Experimental Substation, Delhi, F. A. Stinson, B.S.A., M.Sc.

MANITOBA

Superintendent, Experimental Farm, Brandon, R. M. Hopper, B.S.A., M.S.
Superintendent, Experimental Station, Morden, W. R. Leslie, B.S.A.
Officer-in-Charge, Pilot Flax Mill, Portage la Prairie, E. M. MacKey, B.S.A.

SASKATCHEWAN

Superintendent, Experimental Farm, Indian Head, W. H. Gibson, B.S.A.
Superintendent, Experimental Station, Scott, G. D. Matthews, B.S.A.
Superintendent, Experimental Station, Swift Current, G. N. Denike, B.S.A.
Superintendent, Experimental Station, Melfort, H. E. Wilson, B.S.A.
Superintendent, Experimental Substation, Regina, J. R. Foster, B.S.A.
Superintendent, Forest Nursery Station, Indian Head, John Walker, B.S., M.S.
Superintendent, Forest Nursery Station, Sutherland, W. L. Kerr, B.S.A., M.Sc.

ALBERTA

Superintendent, Experimental Station, Lacombe, G. E. DeLong, B.S.A., M.Sc.
Superintendent, Experimental Station, Lethbridge, A. E. Palmer, B.Sc., M.Sc.
Superintendent, Experimental Station, Beaverlodge, E. C. Stacy, B.A., M.Sc.
Superintendent, Dominion Range Experiment Station, Manyberries, H. F. Peters, B.Sc.
Officer-in-Charge, Experimental Substation, Fort Vermilion, V. J. Lowe

BRITISH COLUMBIA

Superintendent, Experimental Farm, Agassiz, W. H. Hicks, B.S.A.
Superintendent, Experimental Station, Summerland, R. C. Palmer, M.S.A.
Superintendent, Experimental Station, Prince George, F. V. Hutton, B.S.A.
Superintendent, Experimental Station, Saanichton, J. J. Woods, B.S.A., M.Sc.
Officer-in-Charge, Experimental Substation, Smithers, W. T. Burns, B.S.A., M.Sc.

YUKON AND NORTHWEST TERRITORIES

Officer-in-Charge, Experimental Substation, Whitehorse, Y.T., J. W. Abbott
Officer-in-Charge, Experimental Substation, Fort Simpson, N.W.T., J. A Gilbey, B.S.A., M.Sc.

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1949